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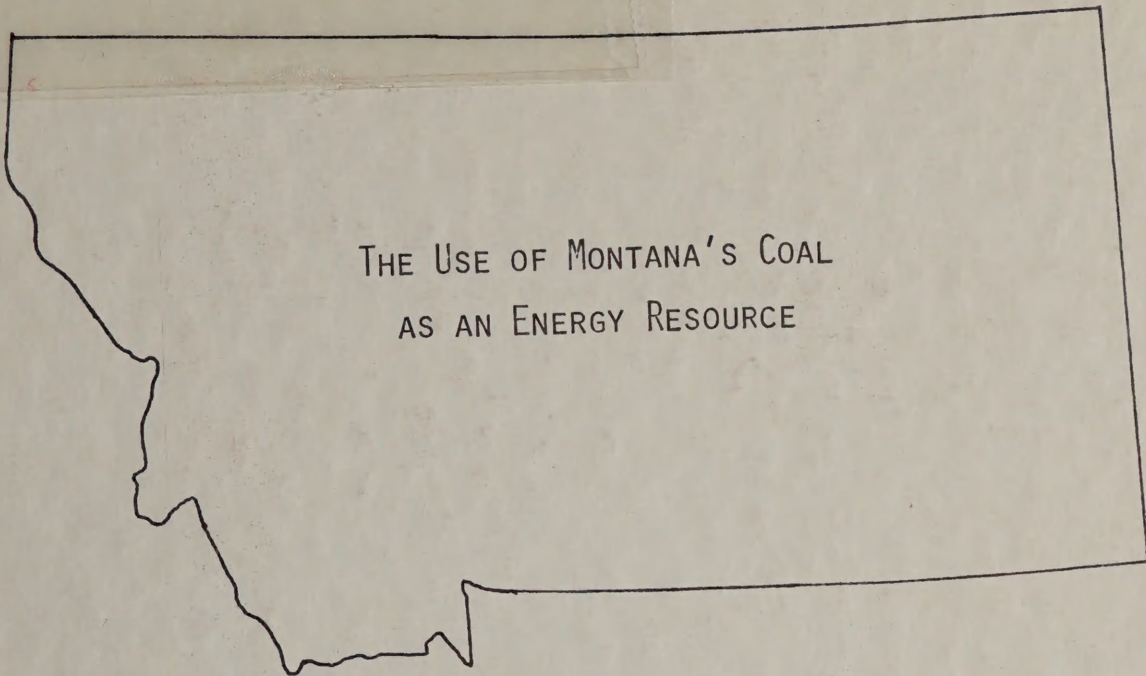

The Use of Montana's Coal as an Energy Resource

A Report to

The Montana Environmental Quality Council

by

Tom Finch

July 15, 1974

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as an Energy Source

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Abstract

The Use of Montana coal as an energy source has been approached from an engineering-economic view. Coal reserves are annotated and discussed. Montana has no proven underground reserves but about 42 billion tons of proven surface reserves. Alternate extraction methods are investigated in an attempt to justify and predict the underground mining characteristics, physically and economically, of reserves now considered surfaces minable. This could be done at cost comparable with other underground operations while suffering surface subsidence and also at lower recoveries than experienced in surface mining.

The market potential of Montana is examined from today's view and from a what if philosophy. Undoubtedly Montana has a firm place in a gradually growing steam-coal market. Possibilities of gasification or liquefaction exist but are unpredictable even though Montana coal meets the requirements of such use.

Introduction

General

The abundant availability of energy is fundamental to the strength and economy of the United States. The annual consumption of all forms of energy in the United States has increased seventeen fold in the past century, while the population has increased some five fold. Coal, as an energy source, has lost its leading position to natural gas and petroleum. However, the coal industry is experiencing a period of rapid growth which began in the early sixties.

The forms of energy available which are important or may be of importance in the future include fossil fuels, geothermal energy, tidal energy, intercepted solar radiation and nuclear energy by both fusion and fission. Presently only the fossil fuels, nuclear energy and small scale tidal and geothermal energy are being utilized commercially in the energy market.

The fossil fuels include coal, oil shales, tar sands, natural gas and petroleum which are rich in chemically stored energy. The minable coal resources of the world are estimated to be 7.3 trillion metric tons and this is only 50 percent of the total coal in the ground. The United States coal resources are estimated to be 1,581 billion tons (1). The major recoverable energy resources of the United States are shown in Table 1. Although there are possibilities for energy supply from other sources in the future, it appears that considerable technology will be necessary in order to make these possibilities economically feasible. On the other hand the outlook for fossil fuels,

especially coal, appears to be confirmed for at least another 50 years despite development in nuclear energy.

TABLE 1 RECOVERABLE ENERGY RESOURCES OF THE UNITED STATES. (2)

Resource	Reserves in Quintrillion BTU
Coal	30.0
Natural Gas	1.5
Oil	2.0
Uranium U_3O_8	1.5
Uranium (Breeder)	730.0

Future Energy Demand

Between the years 1971 and 2000, the United States will consume more energy than it has in its entire history. By the turn of the century, the annual U.S. demand for energy is expected to double and that for the world, to triple. These projected increases will try man's ability to explore, discover, extract, and beneficiate the fuels in volumes necessary, to transport them safely and to dispose of effluent wastes with minimum harmful environmental effects. Considering the difficulties experienced at present in mining safely without environmental damage, in finding acceptable locations for new power plants and in controlling stack emissions from existing plants, the energy projections for the year 2000 indicate the need for a thorough evaluation of the available options and cautious planning. (3)

Figure 1 shows the energy demand for the U.S. calculated to the year 1985 when the annual energy utilization rate will be nearly double the present rate. Figure 2 shows the growth of coal requirements of the U.S. for traditional and possible new energy adaptations that use

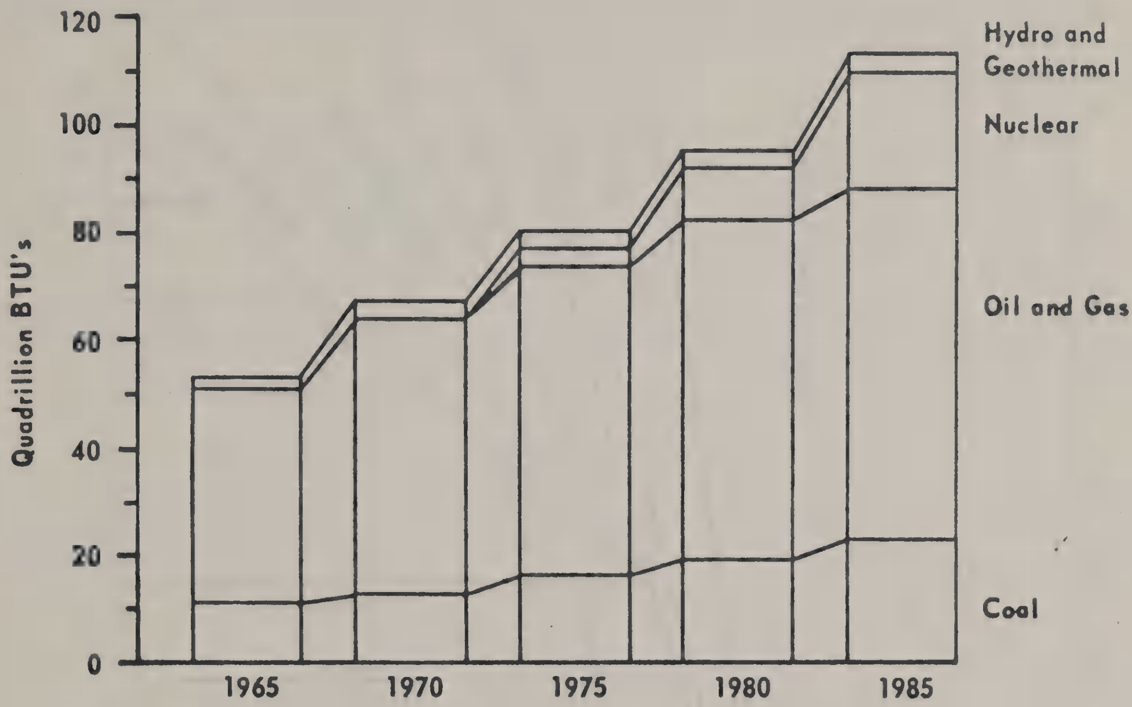


Figure 1 U.S. ENERGY DEMAND TO THE YEAR 1985 (2)

GROWTH OF COAL SUPPLY REQUIREMENTS (4)

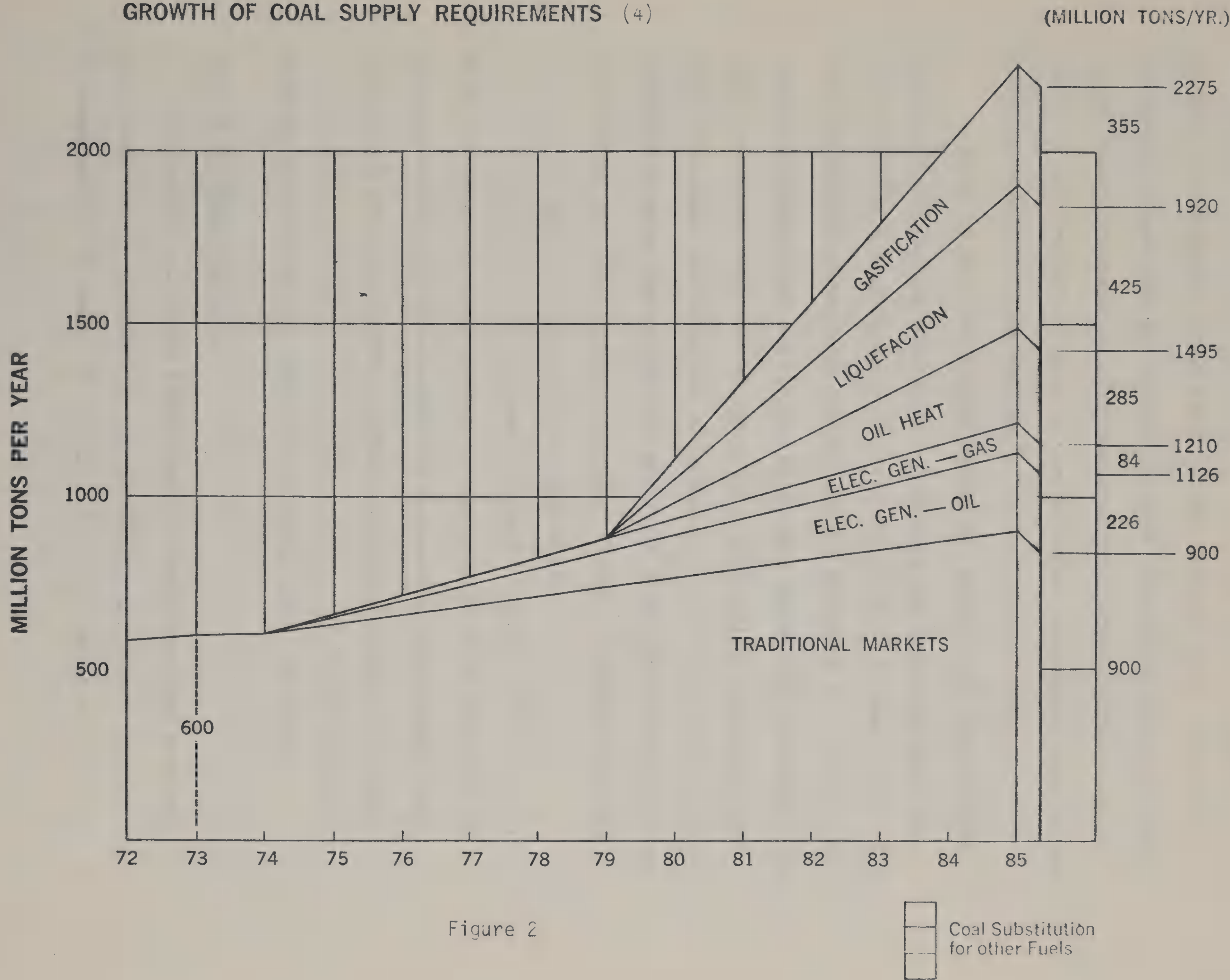


Figure 2

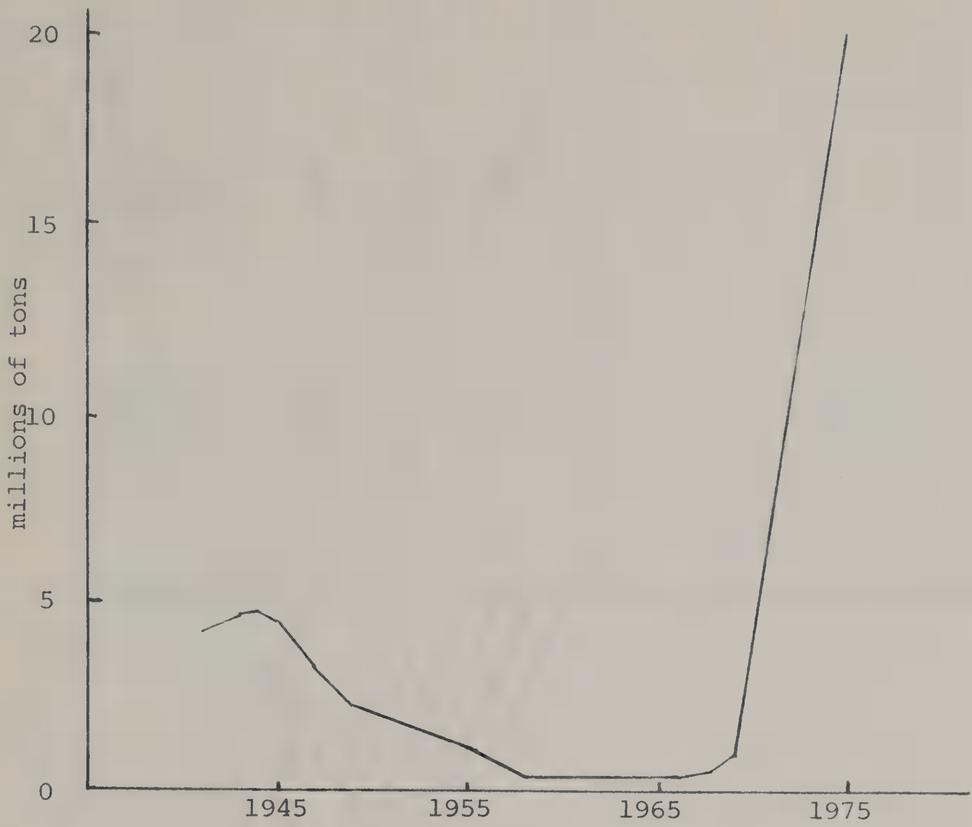
coal as a base. Figure 3 shows past production and future coal demand for Montana. These three graphical displays tie Montana's coal picture to that of the nation. They indicate that Montana could produce up to 7% of the nations coal and possibly 1.5% of the nations energy by 1985. These figures are based on a Montana production of 60 million tons per year. A more realistic figure in view of recent development rate is one-third to one-half of that however.

In order to meet the growing demand for energy, all fuels will be required in increasing quantities. Economics and technology must also assure that each fuel be put to the use for which it is best suited. (5) Coal has gradually overtaken natural gas and petroleum in the field of electricity generation and the use of nuclear energy has increased. Low cost strip-mined coal will be competitive with nuclear energy for some time. Forecasts indicate that as technology in the field of coal gasification progresses, demand for coal may shift from electricity generation to synthetic gas and liquefied products. Figure 4 indicates the effect of synthetic gas on increased coal requirements.

If coal gasification becomes feasible by the late 1970's or early 80's, the demand for coal may not decline as rapidly as predicted. Although there is no direct answer to forecasting energy demand and fuel usage, coal should have an assured position throughout the foreseeable future because of its abundance, widespread distribution and chemical versatility. (5) This is indicated, again, in Figure 2.

Coal as an Energy Resource

In the light of future predictions for energy and fuel demands, coal usage will be prevalent in the electricity generation industry for at least another 50 years. Presently the Applachian region of the



Montana Coal Production, by year

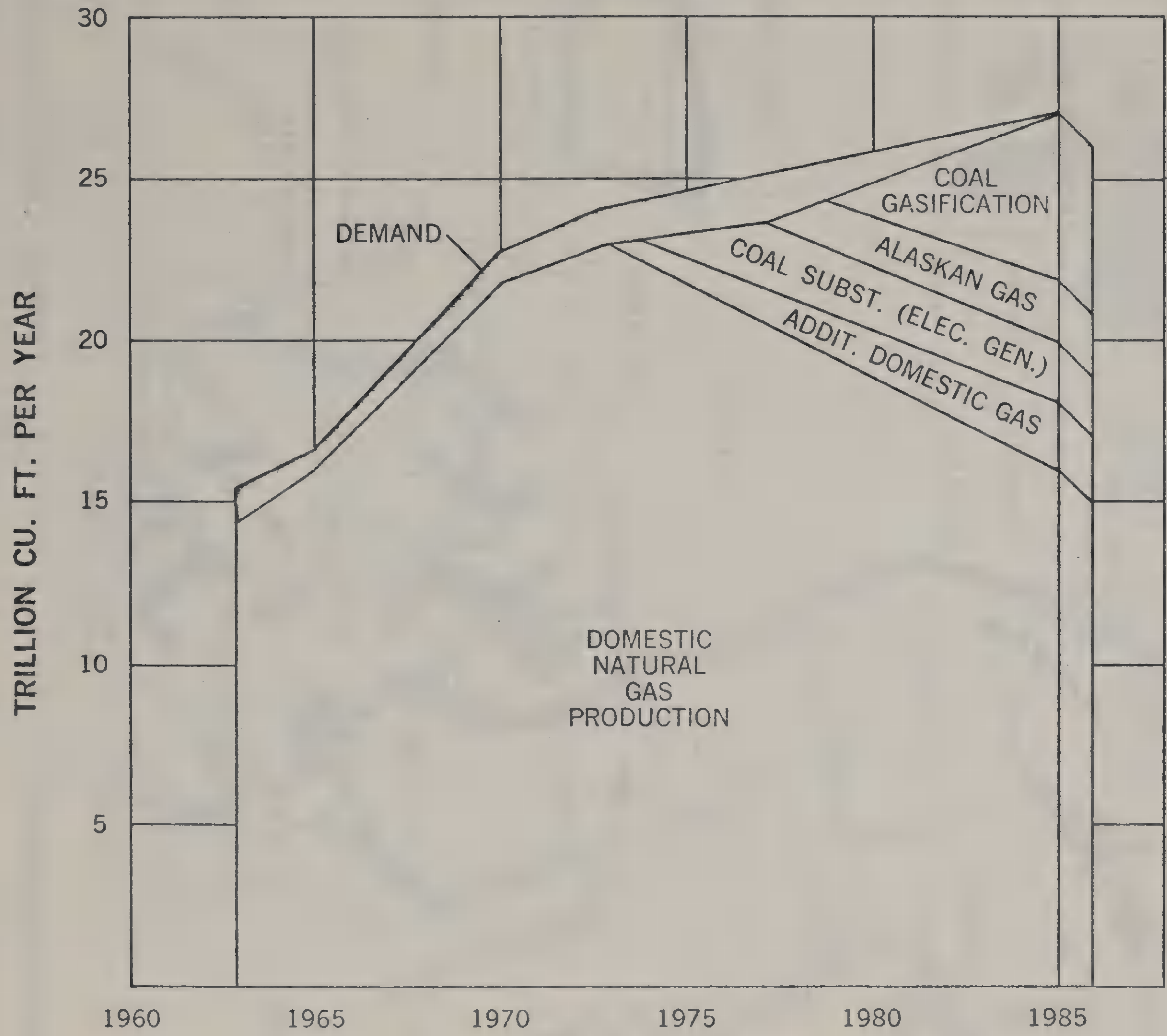
Figure 3

United States produces the bulk of the coal to satisfy this demand. Although butuminous coal is leading in production ahead of both anthracite and lignite, future indications are that production from Western fields will increasingly enter the coal market at the expense of eastern bituminous production. This is partially due to the growing scarcity of easily minable eastern coal deposits.

The largest coal deposits in the country are located just east of the Rocky Mountains, in the states of Montana, Wyoming and North Dakota. Figure 5 shows the location of the major deposits in Montana and adjacent states.

U.S. NATURAL GAS—DEMAND—SUPPLY (4)

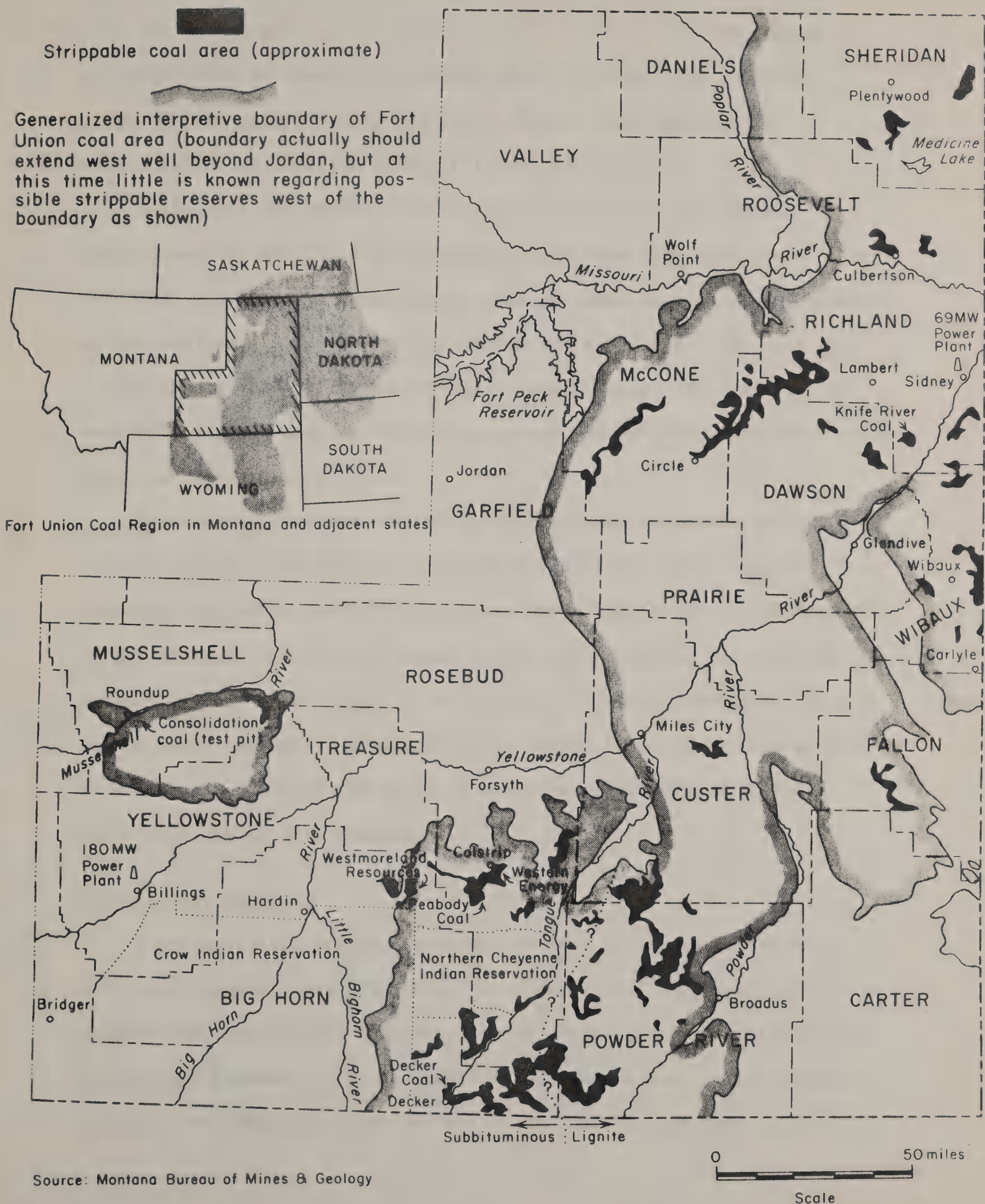
CASE "B" ENERGY INDEPENDENCE



1985 Trillion Cu. Ft./Yr.	1985 Coal Equivalent Mil. Tons Per Yr. Total	Capital Requirements $Bil. 1974-85
27	439	116
5.0	355	36
2.0		17
2.0	84	7
2.0		
16.0		56

Figure 4

FORT UNION COAL AREA IN EASTERN MONTANA



Source: Montana Bureau of Mines & Geology

The bulk of these coal seams are located at depths of 10 to 150 feet and are well suited for strip mining with recovery rates greater than 90% within the confines of the mine. Although the BTU content of these coals is lower than eastern coals, ranging from 5,500 to 8,500 BTU/lb, western coals are low in sulfur which makes them desirable for utilization in electricity generation.

Since coal gasification is closer to becoming feasible than developments in the field of oil shale production at a time when crude oil supplies are diminishing, large volumes of coal will continue to be required to meet the energy demands of the future. Because of its abundance, especially in the large western deposits, coal will be available to meet part of the energy demand through both coal gasification and electricity generation.

Potentially, Montana coal as an energy resource exists in quantity and quality to contribute favorably to our nations energy demands. The fulfillment of that contribution is not yet a reality nor is it dominant on the horizon. Conflicting goals range from promoters who view coal as dollars for the adept lessor to ecologists who visualize Montana as a sacred cow. Hopefully, a middle ground exists for orderly development of another of our rich resources in a manner acceptable to industry and to the citizens of Montana.

Montana Coal Reserves

A great deal of misunderstanding has been displayed in the news media and elsewhere over the terms "coal resources" and "coal reserves." An unfortunate effect of this has been to create terrible confusion as to the true picture of the availability of minable coal in the United States. Even high government officials and legislators have apparently

failed to grasp the fact that the two terms represent different categories of material (6).

The term resource describes a concentration of naturally occurring materials in such form that the economic extraction of a commodity is currently or potentially feasible. Reserves are limited to that portion of the resource which can be economically and legally extracted at the time of determination. From this differentiation, at present Montana has no legitimate reserves of minable underground coal reserves. A substantial tonnage of strippable reserves has been deliniated however.

To further clarify resources, adjectives such as measured, indicated and inferred precede resource estimates. Measured coal resources are those for which tonnage is computed from dimensions revealed in outcrops, trenches, mine workings and drill holes. The points of observation and knowledge of the deposit are well enough defined to compute the tonnage within 20 percent of the true tonnage. Indicated resources are those which have a tonnage computed partly from specific measurements and partly from projection of data on the basis of geologic evidence. Inferred resources consist of quantitative estimates based on broad knowledge of the geologic character of the region and for which few measurements are available. (5)

With the background of definitions well in hand, the energy crisis which bloomed last year has confused the measurement of resources again. Since coal resources are measured in tons, oil in barrels and natural gas in cubic feet, any effort to correlate our energy resource dimension must use a common denominator---Btu. A Btu is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. To use such a small unit of measurement (one ton of typical

Montana sub-bituminous contains 17 million Btu), national energy requirements are expressed in quadrillion (10^{15}) Btu. The term quadrillion is also stated in the form of Q.

Btu equivalents of common energy sources are:

Crude oil, per barrel	5,800,000
Natural Gas, per cubic foot	1,032
Coal, per ton - eastern	24,000,000
Electricity, per kwh	3,412

From the list above, it is obvious that Btu does not clearly define resource requirements as the Btu value of all fuels is variable both regionally and locally. The 1973 gross U.S. energy input was about 76Q. (7) To supply this, 3,000 million tons of eastern coal would suffice while 4,470 million tons of Montana coal would be required. This report will discuss coal resources and reserves in terms of tonnages.

Having supplied resources with three adjectives which define their accuracy of measurement, one step further will close more precisely on reserves. Realistically, reserves are those which the coal mining industry is interested in and those which contribute substantially to our energy input. The indication here being that the more profitable reserves will be used before those more difficult and expensive to attain. Reserves of economically exploitable coal are defined as material having a thickness over 28 inches and less than 1000 feet of overburden. This is further thinned by classifying "economically available reserves" as those excluding lignite and intermediate--thickness (28 to 42 inch) bituminous and sub-bituminous seams. (7)

To Montana, the previous limitations cut a considerable amount of our coal resources. However, local consumption of lignite is obviously economically viable. Also, considerations of low sulfur

coal value has not been accounted. Objectiveness is the point however, and the previously listed limitations do control well over 90 percent of the U.S. market. The definition of reserves over resources cuts 1,581 billion tons of U.S. coal resource to 209 billion tons of economically available reserves, 13 percent of the resource at today's market.

The preceding commentary not only indicates the status of U.S. coal energy, but also shows the importance of understanding resource and reserve estimates. Another important aspect demonstrates that coal resources can change drastically as interest increases. On January 1, 1968 Montana had strippable reserves of 6.897 billion tons (8). By the spring of 1974, Montana had an accountable 32 billion tons of strippable reserves (9), all east of the Little Big Horn and south of the Yellowstone River exclusive of Indian land. Montana strippable reserves are now estimated to be 42.5 billion tons and this alone approaches the U.S. Bureau of Mines figure of 45 billion as indicated in IC 8531 (8). The Federal figure reduces the resources by an 80 percent recovery factor and deletes coal considered to be unminable such as that steeply dipping, outcrops, under surface instalations of perminence, etc. In fact, a great portion of Montana's "reserves" will undoubtedly be unrecoverable. Table 2 lists the most recent strippable reserves by Matson.

<u>Minable Underground Reserves</u>

From the preceding discussion, a flat statement that Montana has little or no underground minable coal reserves should come as no shock. It is true that there exists considerable amounts of coal in the ground and that prior to 1920 sizeable tonnages were produced. Estimates of

MONTANA BUREAU OF MINES AND GEOLOGY

Table 2. - Strippable subbituminous and lignite coal fields, eastern Montana

No. on map	Name of field	Coal bed	Est. reserves in millions of tons	Acreage	Average tons/acre	Ash[1]	Sulfur[1]	Btu[1]
1	Decker	Anderson-Dietz 1&2	2,239.99	25,523	87,763	4.0	.40	9,652
2	Deer Creek	Anderson-Dietz 1&2	495.65	14,214	35,397	4.0	.50	9,282
3	Roland	Roland	218.04	12,076	18,055	9.2	.74	8,164
4	Squirrel	Roland	133.41	6,208	21,490	5.5	.29	7,723
5	Kirby	Anderson	216.52	5,655	38,285	4.2	.32	8,328
		Wall	473.69	5,952	79,579			
		Dietz	834.35	17,516	47,630	5.8	.59	8,509
		Canyon	158.53	4,066	38,983	5.8	.24	8,789
6	Canyon	Wall	1,884.25	23,859	78,974	4.6	.30	9,088
		Brewster-Arnold	65.86	2,067	31,859	7.5	.40	8,444
7	Birney	Brewster-Arnold	180.55	6,969	25,905	5.1	.41	9,055
8	Poker Jim Lookout	Anderson-Dietz	872.65	19,609	44,501	5.2	.37	7,925
9	Hanging Woman Cr.	Anderson	1,583.29	30,547	51,830	4.9	.29	8,496
		Dietz	1,120.96	43,654	25,678	5.5	.33	8,078
10	West Moorhead	Anderson	883.74	19,660	44,949	5.3	.36	8,296
		Dietz	397.49	20,416	19,469	4.1	.41	7,990
		Canyon	690.19	22,547	30,611	5.6	.45	8,055
11	Poker Jim O'Dell	Knobloch	373.29	7,890	47,311	5.1	.22	8,846
		Knobloch	564.78	7,187	78,581			
12	Otter Creek	Knobloch	2,075.55	25,791	80,475	4.7	.36	8,468
13	Ashland	Knobloch	2,696.20	27,200	99,125	4.8	.15	8,421
		Sawyer A & C	357.49	20,262	17,643	4.9	.49	7,883
14	Colstrip	Rosebud	1,439.26	33,379	43,118	9.5	.12	8,836
15	Pumpkin Creek	Sawyer	2,426.50	45,695	53,102	7.5	.34	7,438
16	Foster Creek	Knobloch	708.13	27,801	25,470	7.8	.76	7,573
		Terret	460.87	27,462	16,782	5.8	.21	7,770
		Flowers-Goodale	258.90	14,444	17,924	7.8	.51	7,553
17	Broadus	Broadus	739.82	18,429	40,142	7.2	.27	7,437
18	East Moorhead	T	525.21	15,559	33,756	6.2	.57	7,120
19	Diamond Butte	Canyon	418.02	21,363	19,566	4.8	.43	7,330
20	Goodspeed Butte	Cook	628.95	13,446	46,775	10.6	1.63	6,771
21	Fire Gulch	Pawnee & Cook	336.69	8,486	39,674	3.8	.33	7,739
22	Sweeney-Snyder	Terret	326.33	10,921	29,880	9.1	.11	8,175
23	Yager Butte	Elk & Dunning	1,175.86	26,924	43,673	4.8	.33	7,646
		Cook	312.02	14,507	21,507	6.7	.63	7,254
24	Threemile Buttes	Canyon & Ferry	225.40	13,836	16,289	5.5	.94	6,867
25	Sonnette	Pawnee	320.25	8,224	38,940	9.8	.88	6,964
		Cook	362.98	10,470	34,668	8.1	1.23	6,891
26	Home Creek Butte	Canyon & Ferry	217.21	4,851	44,774			
27	Little Pumpkin Creek	Sawyer A&C, D, X, & E	215.83	8,534	25,290			
28	Sand Creek	Knobloch	267.34	5,952	44,915	6.6	.30	7,340
29	Beaver-Liscom	Flowers-Goodale & Terret	135.87	8,851	15,350	8.1	.96	8,102
		Knobloch	491.62	17,075	28,791	7.7	.50	8,027
30	Greenleaf-Miller Creek	Rosebud, Knobloch, and Sawyer	453.71	14,918	30,413	7.5	.71	8,422
31	Pine Hills	Dominy	193.87	6,022	32,191	7.2	.53	7,293
32	Knowlton	Dominy (M & L)	747.51	19,613	38,112	7.1	.41	6,710
		Dominy (U)	120.31	4,448	27,048	5.6	.38	6,645
33	Sarpy Creek	Rosebud-McKay	1,500.00	42,373	35,400	6.5	.50	8,600
34	Cheyenne Meadows	Knobloch	1,200.00	13,560	88,500	4.1	.40	8,400
35	Little Wolf	Rosebud-McKay	314.00	7,411	42,370			
36	Jeans Fork		90.00	3,800	23,685			
37	Wolf Mountains		1,922.00	31,000	62,000			
38	Lame Jones	Dominy	150.00	10,593	14,160			6,020
39	Lamesteer	Harmon(?)	35.00	1,978	17,700			6,332
40	Wibaux	C	643.00	18,518	34,720	7.9	.90	6,050
41	Little Beaver	C	134.00	8,445	15,865			
42	Four Buttes	C	91.00	5,180	17,570			6,140
43	Hodges		10.00	807	12,390			
44	Griffith Creek		10.00	568	17,700			

MONTANA BUREAU OF MINES AND GEOLOGY

Table 1. – Strippable subbituminous and lignite coal fields, eastern Montana

No. on map	Name of field	Coal bed	Est. reserves in millions of tons	Acreage	Average tons/acre	Ash[1]	Sulfur[1]	Btu[1]
45	Smith-Dry Creek	G	150.00	8,475	17,700			
46	O'Brian-Alkalie Creek		150.00	8,475	17,700			
47	Breezy Flat	Pust	200.00	7,062	30,090	6.7	.50	6,660
48	Burns Creek	Pust	200.00	7,062	30,090			
49	N.F.Thirteen Mile Creek	Pust	225.00	5,085	44,250			6,880
50	Fox Lake	Pust	46.00	2,166	21,240			6,880
51	Lane	Lane	561.00	44,582	12,390			7,150
52	Carroll	Carroll	345.00	29,780	11,584	5.5	.30	7,400
53	Redwater River	S	642.00	24,181	26,550	6.1	.40	7,400
54	Weldon-Timber Creek	S	724.00	25,565	28,320			7,660
55	Fort Kipp	Ft. Kipp-Ft. Peck	331.00	14,500	22,830	4.6	.20	6,110
56	Lanark	Lanark	100.00	3,531	12,390	6.3	.40	6,853
57	Medicine Lake		58.00	3,740	15,510	7.2	1.00	6,870
58	Reserve		246.00	18,231	13,495	7.6	.40	6,599
59	Coal Ridge	Coal Ridge	150.00	19,200	17,700	7.5	.40	5,830
60	Carpenter Creek	Carpenter	50.00	3,211	14,015	6.5	.40	9,270
61	Charter	Mammoth	60.00	3,210	17,700	6.0	.90	10,190
62	Little Sheep Mtn.	A&C	200.00	10,272	19,470			
		TOTAL	42,561.93	1,152,640				

[1] "As received" basis (where more than one sample available, figures given are average figures).

By Robert E. Matson

twenty-five years ago (10) accounted for 2.36 billion tons of bituminous coal, 132 billion tons of sub-bituminous and 87.5 billion tons of lignite. Due to more conservative guide lines, this total of 222 billion tons is down 159 billion tons from a 1928 estimate of 381 billion tons. If the 1974 industry standards of deleting lignite and coal under 42 inches is used, the 1949 figures are reduced to 1 billion tons of bituminous coal and 41.85 billion tons of sub-bituminous coal that exist as measured or indicated resources in Montana. A United States Geological Survey bulletin of 1967 (5) uses the same figures as presented in 1949. Another publication (1) again repeats the 1949 data and classifies it to January, 1972. The quoted resource tonnages include those now classified as strippable.

With this historical overview, it is obvious that Montana coal resource estimates are in a state of flux. Resource estimates always change but usually not as much as Montana is suffering as interest in Western coal grows. Underground reserve calculations are compounded in difficulty because previous work averaged coal thickness to arrive at a tonnage figure. A coal seam changing from one foot to seven feet thick was given an average thickness of four feet. While such maneuvering simplifies geologic calculations, it gives no indication of mining suitability. Other factors depreciating minability such as thin partings of shale were not considered in thickness quotes. Modern high production mining methods handle such complications poorly. In the early days of hand mining, much of this waste parting was sorted underground.

Figure 6 shows the distribution of coal in Montana. A discussion of the separate areas will indicate the possibilities for underground

Fig. 1 - Map showing distribution of coal in Montana

mining. Since Montana markets are far removed from the resource, underground minable coal will be considered that of at least 5.5 feet thick. The existence and undesirability of thin partings and high sulfur or ash must be considered. The coal areas will be discussed in order of decreasing interest of underground mining.

The Bull Mountain coal field occupies the central part of the Bull Mountain basin in the southern part of Musselshell County and the Northeastern part of Yellowstone County. The Roundup coal bed has been mined in the past south of Roundup. The bed is over six feet thick in the western part and decreases to four feet to the east. The Btu value is over 10,000, of moderate ash and low sulfur. This bed and the Carpenter coal bed in the northeast exist as the most probable underground mining region in Montana. Recent coal industry investigations indicate about a half billion tons of reserves by today's standards.

The Red Lodge region is in Carbon and Stillwater Counties and includes the Montana portion of the Bighorn Basin. The coal beds in this area dip westward steeper than other minable areas of Montana. Historically the Red Lodge area was a strong producer and could conceivably be of interest again. Three fields, the Bridger, Silvertip, and Red Lodge contain coal thick enough to mine. The heat values are similar to Roundup with ash and sulfur slightly higher. One of the last producing underground mines was located here. Due to the pitching nature of the seams, many are minable in only select locations. Thickness of minable coal exists from six to ten feet. No recent estimates of resource are available.

Coal is present over the entire Great Falls area but workable thickness occurs in three separate basins. The Sand Coulee field to the west is the largest. Unfortunately the coal is in two or three benches, separated by thin partings, and ranges in thickness from 8½ feet to 4½ feet. The Otter Creek field is separated into two benches by a bony parting and is three to six feet thick. The Saga Creek field has multiple shale partings and while ranging from six to eighteen feet thick, the net coal is only 2½ to seven feet.

In the Lewistown area, the McDonald Creek field is the largest and best developed. The coal is 2½ to 8 feet thick but separated by two or three partings. Some folds, faults and small lacoliths exist due to the Judith and Moccasin mountains.

The Bearpaw Mountain region extends over 10,000 square miles around the Bearpaw Mountains, eastward to the Little Rocky Mountains and northwest to the Sweetgrass Hills. Coal is present throughout most of this area but tends to be thin and lenticular. In the Milk River field, one bed is as thick as 7½ feet but it is quite impure.

In southwestern Montana several older areas of production exist. The Electric field covers a small area in the south of Park County. Where exposed to mountainous deformation, this coal is of coking quality, but the steep pitches, faults and partings are not acceptable to high production mining. The Lombard field in northern Gallatin County has a small, high Btu, high ash deposit which is thick in some locations. The general deposition of lenticular pockets is not favorable to mining. Some of the first large volume coal mines were in the Livingston-Traul Creek. The coal has good traits with 11,000 Btu, and low ash and sulfur but again the dip runs as high as 65°. This

[illegible]

[illegible] supposed [illegible] [illegible] it is in any [illegible]

ated by thin partings, and [illegible] in thickness five

Then [illegible] the Bear Creek field is separated into two

[illegible] partings are [illegible] to six [illegible] The Red

[illegible] partings [illegible] from six

[illegible] than [illegible], the [illegible] is only [illegible] seven [illegible]

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[illegible] mentioned. The coal is 2½ to [illegible] feet thick [illegible]

and [illegible] partings. [illegible] faults and [illegible]

[illegible] to the [illegible] monocline.

[illegible] The [illegible] Mountain [illegible] covers [illegible] square

around [illegible] Bearpaw Mountains [illegible] on the [illegible]

are [illegible] to the [illegible] hills [illegible]

[illegible] of this area but [illegible] and [illegible]

[illegible], and [illegible] as [illegible] but [illegible] quite [illegible]

[illegible] field [illegible] river [illegible]

[illegible] field [illegible] small [illegible] county,

[illegible] to [illegible] [illegible]

large [illegible] faults [illegible]

high [illegible] The [illegible]

[illegible] which is [illegible] thick [illegible]

The general deposition [illegible] lenticular pockets [illegible]

[illegible] of the first large [illegible] coal mines were [illegible]

[illegible] coal and good [illegible] 11,700 [illegible]

[illegible] 1911 [illegible] as [illegible]

coal may exist in enough quantity to interest companies however.

Further west lignite has formed in old lake beds. Most of the beds are thin and lenticular but in the Drummond and Missoula fields lignite and shale are bedded sequentially up to twenty-five feet thick. The area extent belies development economically.

The preceding discussion is abbreviated from a report by Bateman (11) and indicates that most of the coal in Montana, outside of the sub-bituminous region of the southeast, is either of inferior quantity or quality to be regarded presently as underground reserves. The Bull Mountain area is the most likely area where reserves could be generated in the immediate future.

Underground mining of the lignite area of eastern Montana (see Figure 5) is highly improbable. Economically and physically lignite resources are not considered as underground reserves. Rarely throughout the world is lignite classified as such and the more energy rich countries do not consider lignite a coal. It is apparent however that lignite can compete favorably where transportation is cheap or short and strip mining is utilized.

In the sub-bituminous regions of eastern Montana, Garfield County coals represent the most northerly extension. Here one bed is one to six feet thick and has been mined. Another ranges from nine to twenty feet but as the upper portion contains many partings, only the bottom two or three feet is satisfactory. Many other beds exist but they tend to be thin, impure and of variable thickness.

The primary area of challenge and that which contains coal of thickness and quality to tempt underground mining lies south of the Yellowstone River and east of the Little Bighorn River. This same area

contains the prime strippable reserves of the state. The following section of this report will describe the economic and physical reasons why most strippable coal is not considered an underground reserve. There does exist within this region tremendous amounts of coal that are not considered strippable.

Matson and Blumer (9) have authored a report describing the strippable reserves of the area with an aggregate of 32 billion tons from 32 deposits. Anyone familiar with the area is aware of the robust topography. Relatively flat drainage bottoms give way to rolling hills which disappear quickly into steep sided buttes. The relief of the area is controlled by the north flowing drainage system. Figure 7 shows typical cross sections of coal bearing strata of the region.

The steep sided buttes create the coal resource that can be considered minable by underground methods. Strippable reserves are calculated to a depth of overburden comensurate with the associated coal. In a typical eastern Montana situation, this normally extends reserves near the butte sides, hence the seam of coal continuing beneath the deeper overburden is only minable by underground methods. The situation is similar to contour mining in the east except the coal is below the base of the mountain since it has been extended by strippable limits.

The coal resources beneath the drainage divides of eastern Montana has not been determined to great accuracy. The resource measure is mostly inferred and at best indicated. Some small areas could be calculated as measured, but interest in strippable reserves has not released the money or manpower for this work. Using the 1949 figures of Combo (10) and summing up for the counties covered by Matson and

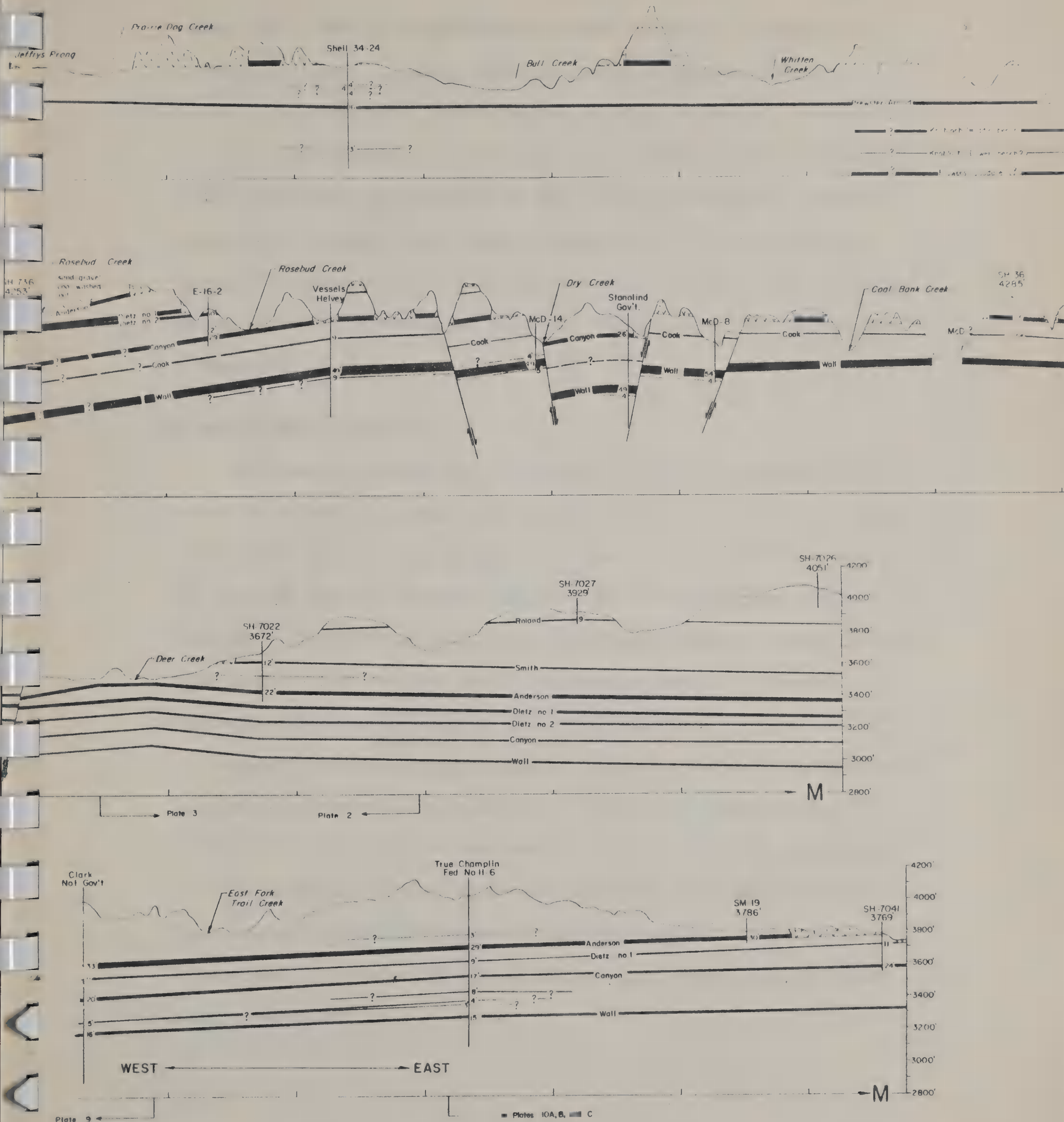


FIGURE 7

REGIONAL CROSS SECTIONS SHOWING STRUCTURE AND CORRELATION

Blumer (9), there is an estimated resource tonnage of slightly over 126 billion tons. If the proven reserves of strippable coal is deleted from this total, there remains 94 billion tons of resource that might be minable by underground means. Reducing this figure by three leaves some 30 billion tons that could be recovered. Although a one-third recovery seems low, consideration of isolated patches, unleasable areas, physical problems such as close seams, edge effects, mining recovery and uncounted unknowns, the figure stated is probably a reasonable estimate.

Minable Surface Reserves

The recent bulletin from the Montana Bureau of Mines and Geology (9) covers Montana's strippable reserves of sub-bituminous coal in detail. Well documented, the report sums a reserve total of 32 billion tons. Not included are the tonnages available from the adjoining reservation land. Reserves on Indian land have been variously quoted, ranging from 10 to 30 billion tons more. Recovery percentage of these strippable reserves is covered in a later section.

Tables 3 and 4 taken from Averitt (12) show the sub-bituminous and lignite resources of Eastern Montana. Note that a great portion (47.7%) of the deposits are unclassified as to thickness. Associated overburden depths are also essential to evaluate for surface reserves. These tables indicate the status of much of Montana's coal resources. To precisely measure our wealth of coal energy, more money and effort must be expended.

Table 3.—Estimated original lignite resources in eastern Montana as determined by exploration and mapping[1]

[In millions of short tons]

County	Measured and indicated resources: In beds 2½ to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	Inferred resources: In beds 2½ to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	Unclassified as to thickness	County total
Carter	366.99	56.40		423.39	40.08			40.08		[2] 463.47
Custer	1,219.46	162.43	117.60	1,499.49	31.22			31.22	668.14	[2] 2,198.85
Daniels									3,964.72	3,964.72
Dawson	301.28	883.85		1,185.13	1,088.98	1,388.38		2,477.36	7,448.00	[2] 11,110.49
Fallon	416.54	247.45		663.99	487.56	18.09		505.65	1,374.44	[2] 2,544.08
McCone					371.00			371.00	24,500.57	24,871.57
Powder River	271.18	177.33	1,335.99	1,784.50	8.87	205.32	435.00	649.19		2,433.69
Prairie	235.46	565.69	160.89	962.04	153.04	147.91		300.95	318.28	[2] 1,581.27
Richland	366.78	1,281.58	830.90	2,479.26	4,436.79	8,213.70		12,650.49	5,955.87	[2] 21,085.62
Roosevelt	657.71	1,591.33	.46	2,249.50	839.24	1,035.49		1,874 73	40.00	[2] 4,164.23
Rosebud									10.10	[2] 10.10
Sheridan	467.60	210.97	100.01	778.58	225.25	1.54		226.79	4,758.45	[2] 5,763.82
Valley									257.93	257.93
Wibaux	573.17	1,436.04	20.18	2,029.39	2,495.72	2,105.75		4,601.47	409.87	[2] 7,040.73
Total	4,876.17	6,613.07	2,566.03	14,055.27	10,177.75	13,116.18	435.00	23,728.93	49,706.37	[2] 87,490.57

Total coal in beds 2½ to 5 feet thick	15,053.92
Total coal in beds 5 to 10 feet thick	19,729.25
Total coal in beds more than 10 feet thick	3,001.03
Total coal in beds of unclassified thickness	49,706.37
Grand total	87,490.57

[1]After Combo and others, 1949, p. 20. [2]Partial estimate.

Table 4.—Estimated original subbituminous coal resources in eastern Montana as determined by exploration and mapping[1]

[In millions of short tons]

County	Measured and indicated resources: In beds 2½ to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	Inferred resources: In beds 2½ to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	Unclassified as to thickness	County total
Big Horn	420.46	1,273.54	2,478.46	4,172.46	322.02	1,717.75	2,685.54	4,725.31	34,602.88	43,500.65
Custer	163.58	1,570.48	779.80	2,513.86					165.00	2,678.86
Garfield	425.66	110.28	26.87	562.81	39.31	10.62		49.93		612.74
Powder River	2,842.72	8,034.63	18,525.97	29,403.32	760.26	3,295.87	7,525.03	11,581.16		40,984.48
Rosebud	1,504.74	4,496.11	4,559.09	10,559.94	1,126.92	4,213.65	5,764.35	11,104.92	17,208.92	38,873.78
Treasure									1,303.66	1,303.66
Total	5,357.16	15,485.04	26,370.19	47,212.39	2,248.51	9,237.89	15,974.92	27,461.32	53,280.46	127,954.17

Total coal in beds 2½ to 5 feet thick	7,605.67
Total coal in beds 5 to 10 feet thick	24,722.93
Total coal in beds more than 10 feet thick	42,345.11
Total coal in beds of unclassified thickness	53,280.46
Grand total	127,954.17

[1]After Combo and others, 1949, p. 19.

Alternate Extraction Methods

Underground Coal Mining Systems

Before selecting and discussing alternate methods of coal mining in Montana, examination of the practicalities of underground coal mining in the rest of the United States would be in order. Should underground coal mining become an economic reality in the Fort Union region, some adaptation of present practice will undoubtedly be involved.

General considerations include a system which provides: (13)

1. The highest possible degree of safety for mine personnel.
2. The lowest cost per ton of product.
3. The maximum coal production per man-shift.
4. The maximum percent recovery of coal per acre of reserve consistent with cost and subsidence rights.
5. Consideration for the ecology of the area.

Important factors for choosing a specific system are:

1. Amount of cover over the coal seam.
2. Type of rock in the overburden.
3. Coal seam characteristics.
4. Quantity of water likely to be encountered.
5. Nature and strength of the floor and roof below and above the coal.
6. Previous or concurrent mining in seams above or below the seam being worked.

Mining systems are generally classified by the equipment used in the mining process. It is possible, however, particularly in older mines, to have more than one or possibly all of the systems prevelent in the U.S. Often a section of one system is instituted on an experimental basis and remains by cost considerations although it does

not improve any of the previously listed system criteria. The principle systems are conventional, continuous, and longwall.

In modern, high production mines, the conventional system represents the ultimate in mechanization of the old hand mining methods. Rubber tired, electrically powered machines produce more with little manpower input. By its nature of simulating an old method, multiple working places and many men are required to produce on a level competitive with newer systems.

The coal is extracted in a sequence of operations with a specific machine for each step. The sequence of events and the typical machinery and manpower required are; 1) An undercutting machine similar to a large mobile chain saw cuts a kerf or slot to break the coal into. 2) A mobile, self feeding auger then drills five to eight blast holes in the face. 3) The holes are loaded with powder or compressed air shells and shot. 4) The shot coal is loaded by a rotating arm coal gatherer and loaded into an alternating pair of shuttle cars. The shuttle cars haul to a local belt for haulage to a main belt system. 5) The clean face area is then roof bolted, rock dusted and the ventilation system is advanced to the face. This system then repeats in a sequential manner.

By virtue of the number of equipment pieces and separate operations, six to seven working places are required. This requirement increases the cost of development headings by shear excess openings but works well in production mining. The management complexity of this system requires an experienced crew and well trained foremen. A conventional crew contains 13 to 15 men and produces 350 tons per shift. This number is quite variable but represents an average in thick seams.

The next system is the continuous section. Here, the conventional steps of undercut, drill, and blast are unitized by one machine, the continuous miner. Continuous mining machines are of one of three types. The highest production machine is the boring type. Two rotating heads revolve flat against the face and tear the coal loose. It is then picked up by an integral chain conveyor and dumped behind the machine. As originally designed, the coal was loaded directly into shuttle cars and then transported to a belt or rail cars. Present practice employs a second loading machine as used in a conventional section to reload the continuously mined coal into the shuttles. This allows the miner to cut coal independent of the haulage or removal system, thus increasing production. Although of high capacity, boring machines are limited to fixed dimensions by their design. This is not advantageous in seams of variable thickness or irregular top.

A second continuous machine is the ripper. It consists of series of parallel cutter chains that saw against the face. A ripper is most simply compared to a set of a half dozen chain saws running in parallel. This machine is very selective and flexible. It is often employed in pillar recovery. Unfortunately, it produces a high amount of coal fines and dust.

The third machine is the milling or drum miner. The cutting action is created with bit wheels on a rotating drum. It is the last of the continuous miners developed and seems to have combined the flexibility of the ripper with the thrust and production of the borer.

Regardless of the machine type, continuous mining sections all function alike. The coal is cut and dumped by the machine, reloaded by a loader into shuttle cars and transferred to belt conveyors.

A typical section will employ a machine operator, a loader operator, two shuttle car drivers, a roof bolter, a utility man and a foreman. These seven face men produce about 50 tons per man per shift in a thick seam (6'+).

The third system is the longwall mining system. This system is a total departure from historic U.S. coal mining methods. Our present longwall is nominally imported from Europe although the method was practiced in the midwest for thin seams in the early 1900's.

The method evolves about a long face (longwall) which is mined by a machine which is moved back and forth, cutting or plowing off coal into a transporting pan or drag chain conveyor. Figure 8 shows a longwall mining section plan view.

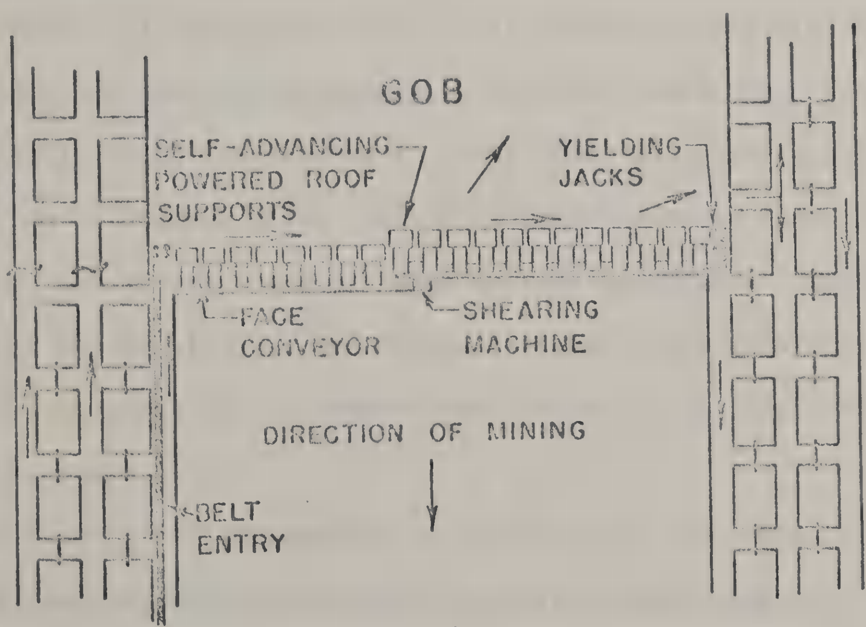


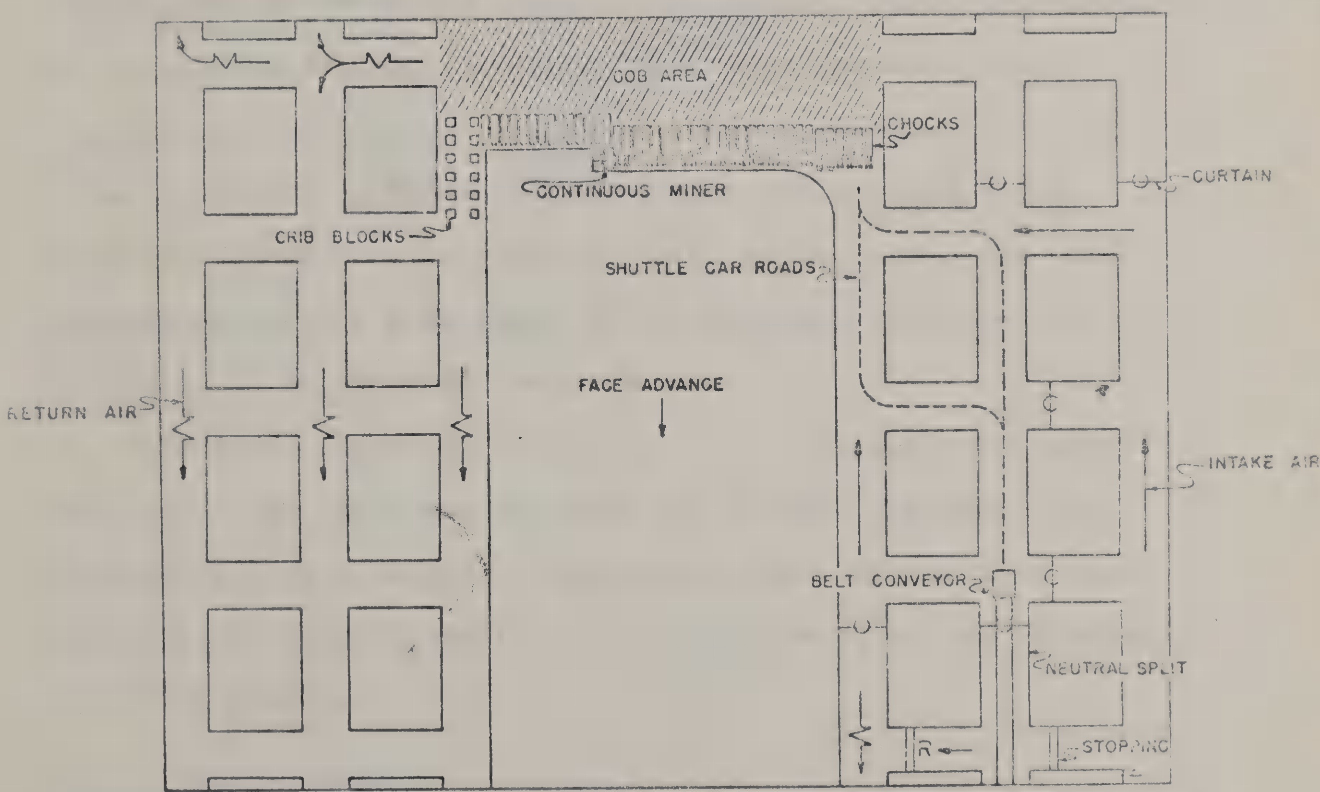
Figure 8-- Longwall Face plan

The coal cutting machines can be of two types, a plow or a shearer. The plow does as defined and plows or cuts the coal by virtue of being dragged across the face by a chain. The shearer has a drum or double drum which rotates into the face. The shearer cuts a deeper slab of coal than the plow. Both machines are capable of high production but the essential element in longwall mining is a properly stressed face. The cantilever position of the roof transfers the unsupported width of overburden load to the long face. This highly stressed face is then very susceptible to failure when penetrated by the longwall cutter. To control the face stress, and to protect and move the equipment, a system of hydraulic props is used. These props or chocks pick up and automatically advance to the face as the cutter passes. They also carry or push the conveyor and cutter into position for the next pass.

Longwall mining systems offer high recovery, good mining under poor roof, and uniform subsidence in shallow overburden. Production per shift is high, ventilation is simplified, and no rock dusting is at the face. Against this, capital equipment cost is high, setup, teardown, and moving costs are high and non-productive. Uniform coal thickness and regular top and bottom are needed and regardless of the number of longwall units, conventional or continuous units are needed for development

A longwall section consists of eight men at the face; a shearer operator and helper, three chock operators, a gate operator, mechanic and a foreman. This crew is backed up by haulage and roof support crews bringing a longwall operation to 13 men per shift. Seven hundred tons per shift yields slightly over 40 tons per man shift in the section or up to 65 tons per man shift for face workers.

Longwall has found favor due to lower per ton costs (higher face productivity), greater extraction tonnage for each ton of development work, greater safety due to the roof support system and simpler system control compared with room and pillar or block mining. (14) The previous production is based on an experienced crew and development work preceding longwalling. Annual production is not a direct product of shift tonnage multiplied by number of shifts as 10% of the time is spent in set up and tear down.



—An experimental plan for shortwall mining now being prepared in eastern Kentucky.

Figure 9

Another system has recently been proposed and is yet in the experimental stage in the U.S. This is termed the shortwall mining system. The apparent advantage is the use of a continuous miner as the coal production machine in a longwall configuration. The same support system of hydraulic jacks is used as with a longwall plan. Shortwall jacks have an extensible cantilever arm since the mining machine cuts a wider (10 feet) pass than a longwall plow or shearer. Figure 9 shows a shortwall mining section.

Use of the continuous miner as the production unit omits the plow or shearer machine thus saving capital. Since the continuous miner must be used for development work regardless, the shortwall system seems to combine the good points of longwall with the flexibility of a continuous machine. A rotating drum continuous miner is the shortwall choice. Coal is transported either by shuttle cars or better yet an extensible, portable, haulage system. The extensible belt system has a head tram car receiving coal from the miner. The tram car also serves as a surge feeder to the drive unit which ties the shortwall belt to the panel haulage belt.

Manpower is suggested as follows: (15) continuous miner operator and helper, tram car driver and drive unit operator, mechanic, two chock setters and a foreman. These eight men are expected to produce similarly to a longwall section but the operation is not yet old enough to predict soundly.

Underground Mining Plans

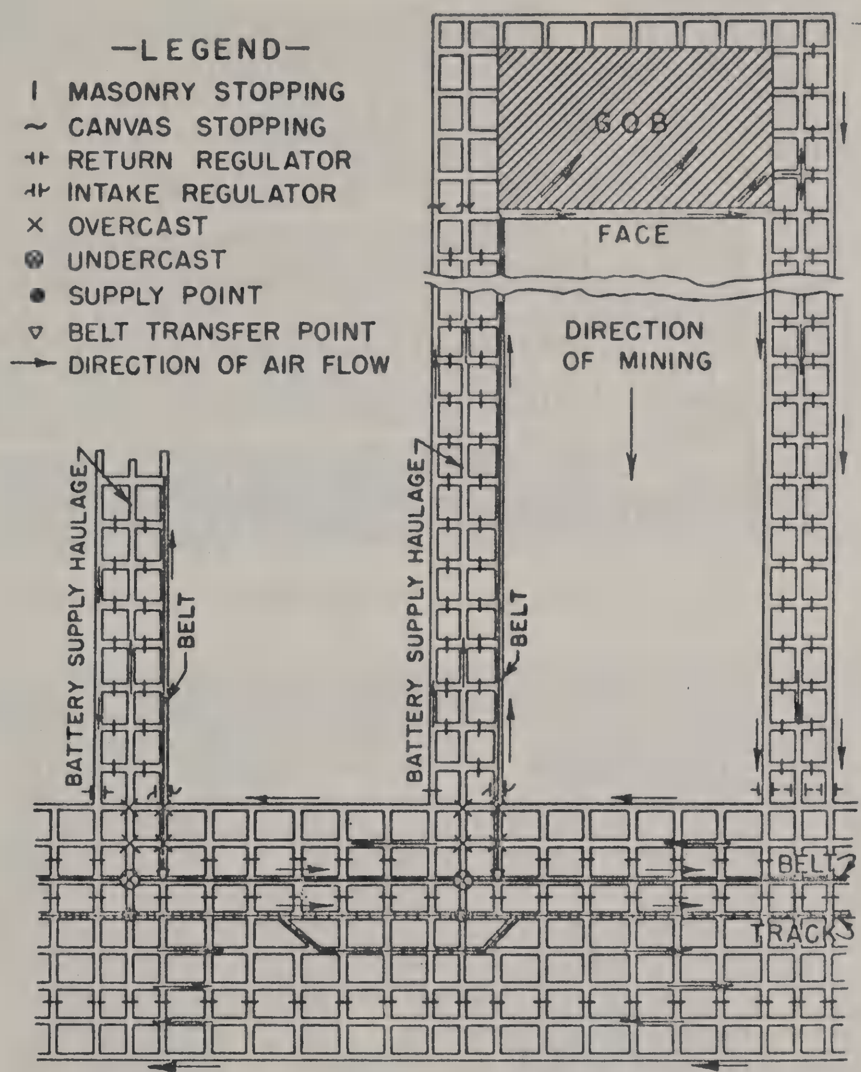
Development for most every system is similar. A block or panel of coal is deliniated by entries driven off of a main or sub main entry. Ideally all development work would isolate a minable block

some 5000 feet long and 600 feet wide. Longwall sections are narrower to reduce the capital expenditures for the support system, see Figure 10. With conventional or continuous systems this deliniation can proceed simultaneously with interior panel development. This multi-development is a function of the quantity of gas expected. An extremely gassy mine first isolates blocks and allows time for the gas to bleed out.

Conventional and continuous sections develop the interior of the panel in one of two methods, a block or room and pillar plan. The block pattern shown in Figure 11 and the room and pillar plan is shown in Figure 12. Both patterns are then mined out on a retreat basis after development reaches the far end of the panel. At this point, total recovery is determined. Poor roof limits the percentage of the blocks or room pillars that may be extracted. The roof must be strong enough to stand while the inby areas are loaded out but weak enough to fail soon afterward in order that great overburden loads aren't transferred to the remaining ribs and blocks. This is the ideal situation which occurs rarely and at that, never in a continuous manner to allow total recovery in the panel.

More coal is lost in the area between panels where ventilation and gas problems compound if adjoining panels are holed through. Often, the barrier pillar of coal between the panel and the main entries cannot be recovered to any extent. Thus, the recovery of coal by a conventional or continuous system usually approaches 50 percent.

Longwall or shortwall systems utilize a narrower panel than conventional or continuous systems, but operating as a total retreating operation they recover a higher percentage of the coal within a panel. Once development headings reach the panel end and are joined, longwall



—Plan for longwall development. Entries are driven by continuous miners.

Figure 10

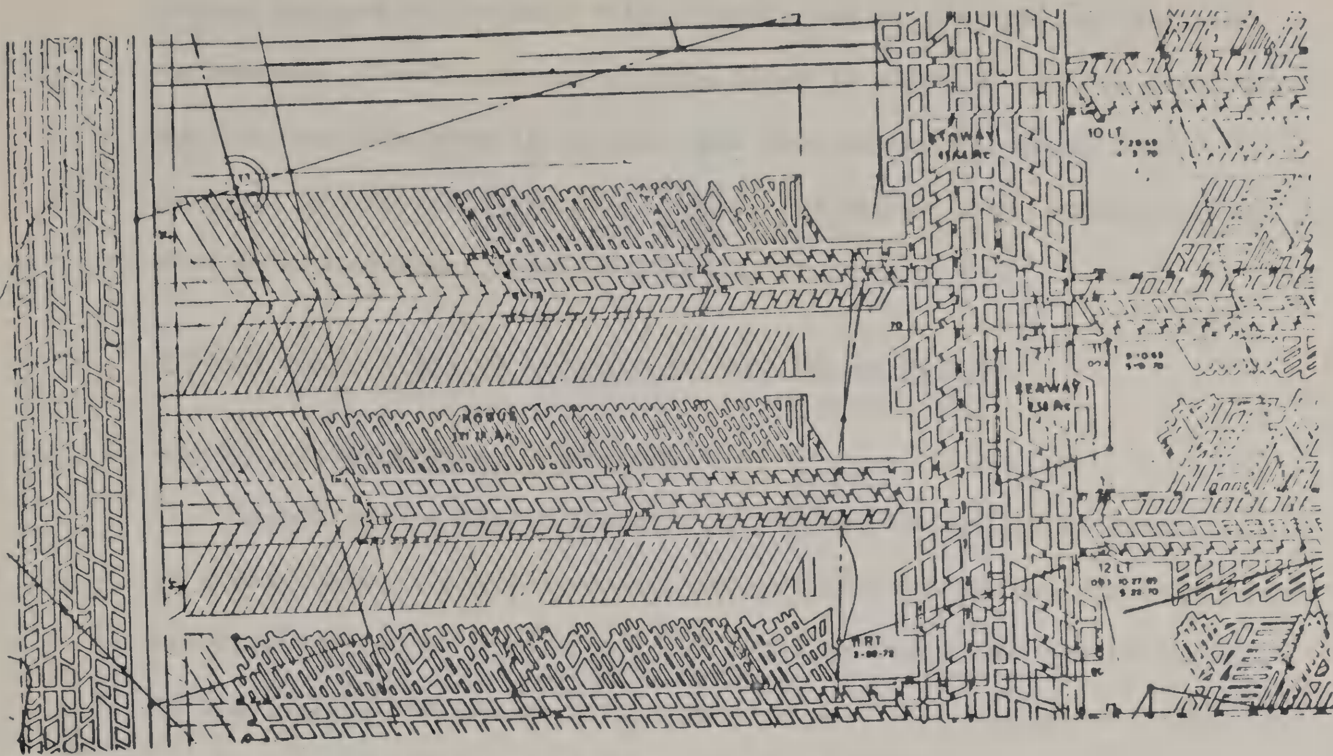


Figure 12. Room and Pillar Panel

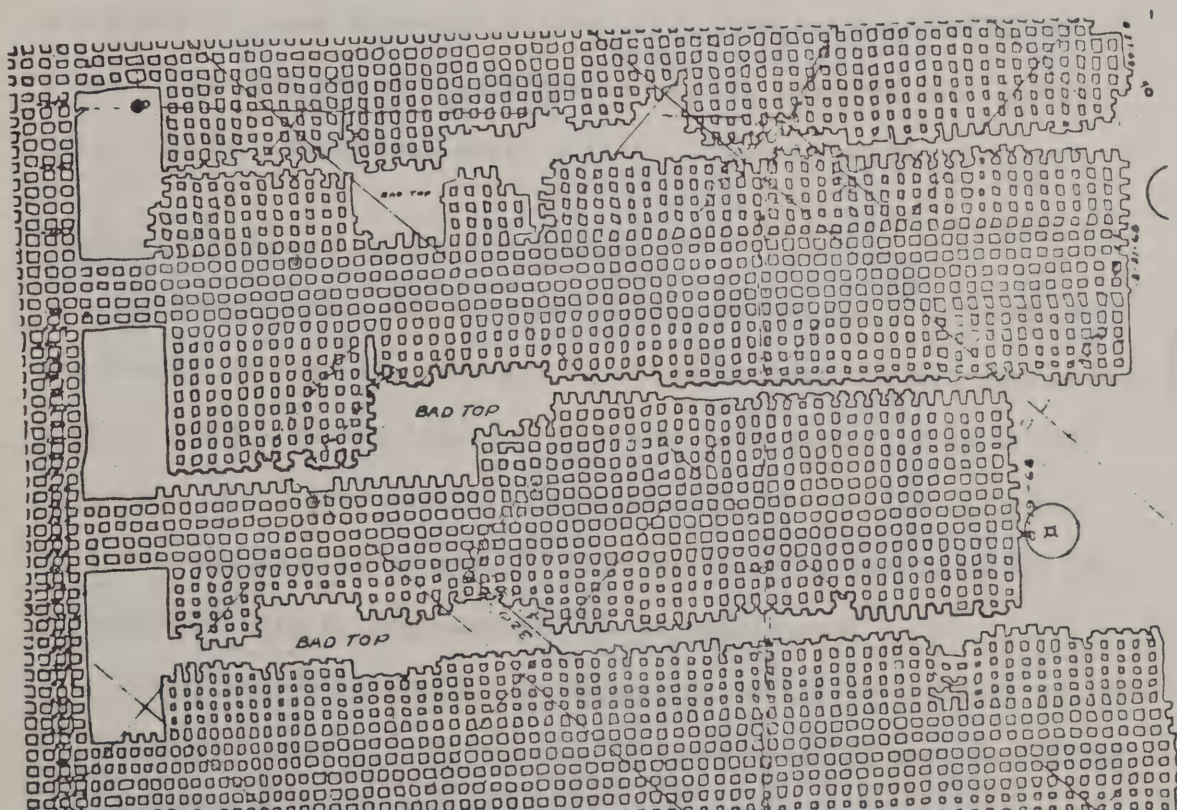


Figure 11. Block Pattern Panel

passes proceed to the main entries until the barrier pillar dimension is reached. Total recovery of this block is expected and the development pillars are extracted if possible but this is not the usual case. Longwall and shortwall recoveries are thus higher than conventional systems and averages about 70 percent.

Montana Application of Underground Coal Mining Methods

Reserves Considered as Underground

Undoubtedly a direct transfer of present technology is possible in mining Montana's underground reserves. The historical mining of underground coal at Roundup and Red Lodge indicate that the feasibility of newer practices can be implemented without undo adaptation. Seams up ten feet thick can be mined in Montana with much the same recovery and costs as found elsewhere in the U.S. Roof and gas conditions as found in Montana are very positive for mining compared with other, less congenial conditions where coal is presently mined.

Reserves Considered as Surface Minable

Conservationists and ecologists have shown a great interest in the feasibility of using Montana's strippable reserves for underground mining. From a mining industry viewpoint this seems ludicrous but certainly an unbiased look at the parameters involved is in order. Only a strong case could justify continuation of a mining method that is unpopular with a large segment of the population.

Before evaluating alternate methods of extracting Montana surface minable coal reserves, the reserves to be manipulated must be defined and described. Strippable Montana coal reserves are mapped to 250 feet

of overburden by the Montana Bureau of Mines and Geology. Although 150 feet is considered the maximum stripping depth by the coal industry, the existence of thick seams at depth complicates the technology transfer from this seam, eastern mining operations. At present, stripping equipment limitations control the minability of a vast portion of our "strippable" reserves. Engineering design has already indicated the possibility of mining to greater depths. The Sarpy Creek Mine of Westmoreland is planning stripping in excess of 200 feet in a multiple seam operation. This is only in the paper stage however and the reality of slope stability and equipment production may be more limiting than hoped for.

Another confusing issue is the existence of multiple seams in reserve calculations. Multiple seams are successfully surface mined throughout the U.S. Variations of coal quantity can cause problems when each seam must be separately mined and marketed on its own merits. Similar quality seams lend to simpler mining practice as blending of the product is possible. Underground mining of multiple seams is much more complex and resource recovery would undoubtedly suffer. This will be discussed in the next section.

Underground Mining of Strip Reserves

Selection of underground coal mining method for Montana's thick strip reserves is difficult from many aspects, both in engineering and economics. Critical problem areas are maximizing resource recovery, minimizing surface subsidence, and adopting an old or creating a new mining method for the unprecedented thick coal seams. The principle immediate problem is the economic competitiveness of Montana coal mined underground.

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...to consider the ... s strip ... g depth by the coal seam. However, the extra ... of ... at ... complicates the techniques transfer from th... ... western mining operations. ... present, ... equipment ... limitations ... the ... of vast ... out ... ... table reserves. Engineering design has already indicated the possibility of mining to greater depths. The ... Coal Mine of Westmoreland is planning operating in excess of 200 feet in a multiple seam operation. This is only in the paper stage however and the ... of slope stability and equipment production may be ... than ... noted for.

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... of ... coal mining ... for Montana's ... as ... result from many aspects, both in engineering and ... problem areas are ... resource recovery ... subsidence, ... of ...

Strippable reserves of Montana are calculated on an economic basis, the method used throughout the industry. Limits of reserves are as follows: less than 10 feet of coal to 100 feet maximum overburden; 10 to 25 feet of coal to 150 feet of overburden; 25 to 40 feet to 200 feet of overburden and greater than 40 feet to 250 feet of overburden. Simple calculations will indicate the probability of surface subsidence on a purely academic basis.

Montana overburden swells about 28% in surface mining. More simply, a one foot cube of in-place overburden will swell to a block one foot square and 1.28 feet high. If a ten foot seam is removed, caving of one foot of overburden will fill the void at a rate of .28 feet of caved material. Thus 10 ÷ 0.28 yields 35.7 feet of overburden caved to fill the 10 foot high void. The relationship is a straight line and can be extended to any limit This preceding example is only numerical and actual practice indicates caving extends to a higher degree than calculated. The reason for this is that surface spoils are quite loose and finer than underground caving. Both of these factors reduce the swell factor for underground material considerably. Another response is more time dependent. As the material caves, it absorbs ground water and compacts to a high degree over the years.

Figure 13 shows an aerial view of the Deitz Mine north of Sheridan, Wyoming. Overburden here averaged about 75 feet and the mined entry was 6 feet. The potholes from caving deliniate the mine in a very orderly manner and indicate a block pattern of mining with surface collapse at the entry intersections. The grid pattern also indicates that the pillars were not recovered and the resource recovery was probably less than 50 percent. A similar condition can be seen near Miles City

Surface Subsidence due to Underground Mining

Figure 13

at the Storm King Mine. Room and pillar mining in Illinois creates long, narrow subsidence similar to a highway borrow pit.

Long term subsidence has an effective swell of about 10%. Thus, 10 feet of coal would cave 100 feet of overburden, 20 feet caves 200, etc. In most western regions this does not disrupt surface facilities. In populated areas of the east and in England, subsidence is a fact and a planned event. High recovery systems such as longwall allow an overall drop in topography rather than the pothole effects of block or room and pillar mining. Most of the reserves classified as strippable in Montana may also be listed as potential subsidence problems if mined underground.

Caving in underground coal mining is a fact. It is a necessary part of the mining system and all coal mines that recover over 30 percent of the coal expect the roof to cave. This caving phenomenon reduces the overburden load that was supported by the pillars during mining. If a continuous and controlled caving is not in effect, tremendous pressures develop and disastrous failures known as "bumps" occur. These bumps are failures of a quick and generally catastrophic nature. Regional stresses can unavoidably cause these bumps. Utah and Nova Scotia mines are noted for this effect as are the metal mines of Idaho.

Adaptation of Mining Methods to Thick Seams

Mining thick seams underground is generally unheard of when the coal exceeds ten feet in thickness. Coal has such a low value per ton that the ingenious and expensive support techniques developed for metal mines which are of lower tonnage and higher value cannot be employed.

Coal strata is not strong enough to mine in the manner of some large limestone and salt mines which have vast rooms supported by large pillars. Even the cheapest method of mining large vertical distances, that of a cemented sand fill, becomes an economic disaster considering the volume of sand that must be found, transported and moved underground to replace a 10,000 ton per day coal operation.

To fit the only applicable method, that of a caving roof, to thick seam mining a series of horizontal slices appears to be the only rational solution. Conventional and continuous mining employ a rigorous pillar system. To be effective, even in thin multiple beds, the pillars must align between slices and in the end, support in a column-like manner. A very thick seam would require close control and undoubtedly a high percentage of coal would be lost to unrecoverable pillars. What is most applicable, therefore, is a system with a minimum of pillar development.

The simplest system to adopt to thick seam underground coal mining is the longwall system. Equipment exists and the technology of application is well established. In fact, such an effort is being extended in Russia, France and England. (16) All of the applications are similar and consist of multiple passes of a longwall shearer and or caving combined.

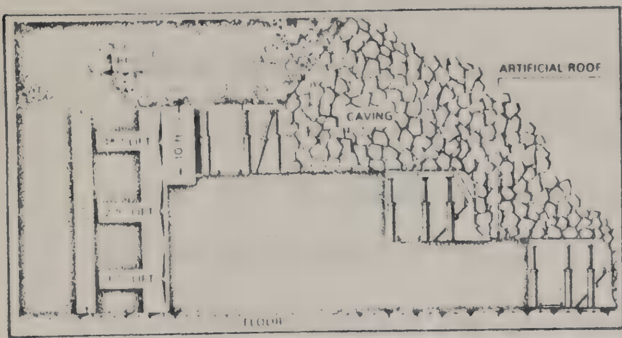
The Russians mine a 16 foot seam by using chocks that extend the full seam height. The shearer's first pass is in the top third after which an extension on the chock advances for roof support. The bottom third is removed and finally the center is dropped after the conveyor is advanced to the face.

The British are mining a seam in excess of 24 feet in a multiple but unconnected slice. The first longwall unit takes the top six feet. A second unit, longer in face length to stagger haulage entries, follows 300 to 500 feet behind in the same panel and removes a second slice. Two feet of coal is left between the sections. A third unit again longer and further behind removes another slice with two feet of coal vertically separating the second and third units. Thus 20 feet of the 24 is recovered, this in itself only 83% recovery.

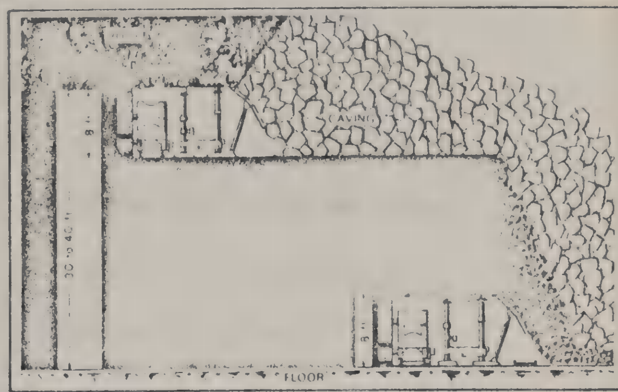
The French have developed a plan using a longwall "integral sublevel cave" (17). A single longwall is developed at the bottom of the seam. A wire net is put under the coal roof cut by the machine. This net remains as the face advances and falls over the back of the chock nets. A second conveyor, on the cave or gob side picks up the caved coal through holes cut in the net. The holes form drawpoints which can be located close enough to reduce dilution from the overburden which of course caves with the upper coal. Figure 14 shows the technique involved.

Since the Russian and British methods employ multiple slices with longwall units, the expected cost would be similar to mining a thinner seam. One obvious plus to the Russian method is the reduced face advance required for tonnage. Less time is spent in moving and, therefore, more time is available for production and this is always more profitable.

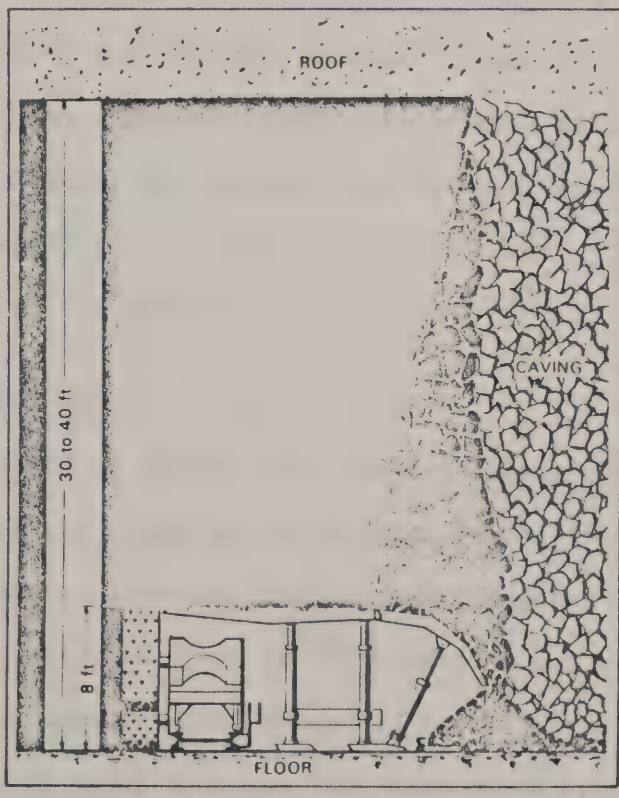
The French system is the most appealing development and undoubtedly could yet be more perfect. The development of full coverage chocks with draw holes available for the caved material should be pursued.



Multi lift method of mining thick coal seams



Sublevel caving in two lifts. Main purpose of face at roof horizon is to destress the coal which forms the floor



Integral sublevel caving. In this method, only a single longwall is developed at the foot of the seam. A shearer and induced caving are employed in mining the coal

FIGURE 14.--Sublevel Caving with Longwall (17)

This should not be too difficult as chocks with gob shields are now available. The wire mesh seems to cause problems and too much hand labor. If developed properly, however, the system would appear to be more economic than any system yet conceived. Costs would be similar to a typical longwall system with capital expenditures on the chocks about double normal. Production would be four to five times normal for the amount of face advance. The cost per ton could be as low as one half a typical longwall section but this is difficult to project as caving and draw methods are a tenuous matter. Dilution and break through of worthless overburden can cause loss of recovery and production. Block caving as practiced in metal mines has a low unit production cost but much ore is lost through improper design and draw techniques. An engineering estimate of coal loss in a thirty foot seam with a eight foot longwall and integral sublevel caving would be at least 20 percent within the mined area. This is in addition to pillar and other losses.

Mining Costs for Montana

Various sources of mining costs are available. The U.S. Bureau of Mines has recently produced two Information Circulars [(18), (20)] which cover underground mining costs and strip mining costs respectively. Both circulars contain analysis for five million ton per year operations and these are reproduced in the Appendix of this report. The production cost underground is based on a six foot seam mined by continuous mining machines as explained earlier in this report. Estimated cost per ton is $6.45 and the selling price is $7.53 per ton. The strip mine operation supposes 25 feet of coal with a maximum of 120 feet of cover and arrives at a selling price per ton of $1.64 with a mining

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[illegible] report. Estimated cost per ton

cost of $1.39 per ton.

Both of these figures are low. The costs quoted by industry for similar underground mining run close to $9.50 per ton. Industry estimates for strip mining in Montana indicate a selling price of $2.25 per ton. Some of the difference in the stripping cost is due to the taxes which rather than the 26 cents per ton quoted in the U.S. Bureau of Mines report are closer to 60 cents (21). Additional 20 percent for inflation over two years brings the figure close to actuality.

Figures are not available for a longwall operation but the underground mining analysis of the U.S.B.M. can be modified by deleting continuous mining units and replacing them with longwall units. An estimated production rate of 400,000 tons per year per unit requires 13 longwall sections. Four continuous sections are needed for development work. The changes for implementing a longwall mine are shown in the appendix. A decrease in labor requirements of 165 men is offset by nearly a 15 million dollar increase in capital equipment. Without calculation of increased labor costs or depreciation of equipment, the net gain is about 17 cents per ton lower mining costs.

The preceding longwall discussion is based on a conventional coal seam. Should implementation of a sub-level caving longwall for thick seams be considered, what would be the costs? Although it is difficult to say, the only increase should be in the form of more expensive gob shield chocks and another conveyor for the caved material. This expense should be offset by higher production per unit. Rather than 13 longwall units for 5 million tons per year, eight to ten would produce the same amount advancing at a slower rate. Manpower

requirements would be similar or slightly increased because the face advances slower but production emerges from both sides of the chocks. In all probability the cost per ton would be very similar to that experienced in thinner seams. Since set-up and tear-down losses occur less frequently, the savings of less downtime might reduce the cost more. Since the idea is mostly academic, a safe estimate would be one comparable with costs experienced now.

Resource Recovery and Mining Systems

Resource recovery and mining systems go hand in hand in Montana coal. Although estimates are variable, of the coal contained within an established mine area, the following lists the expected percent recovery in underground mines by system.

System	Maximum	Norm
Conventional	80%	55
Continuous	80%	55
Longwall	80%	65

U. S. Average is 50% (13)

The recoveries are usually based on a calculated extraction and not measured production. Since coal seams are continuous by nature, sampling or thickness determinations are not as closely controlled as in vein or metal mines. Local variations exist but are not accounted for.

Recoveries differ within each system due to localized roof weaknesses, variation in seam thickness, pillars left under roads, railways, reservoirs and around gas or oil drill holes. If the roof is bad overall, narrow entries and large pillars are the rule and extremely low recovery exists. Normally, this condition is avoided and the coal

is left. Mines with good roof have areas of poor stability and these areas are usually only developed without attempted pillar recovery. Variation of seam thickness is a seemingly small but actually important source of reduced resource recovery. Underground equipment is usually arranged to mine a specific height. Often roof coal is left when shale is the immediate overlying strata as atmospheric moisture causes steady sloughing and associated poor safety conditions. If the underclay is thick or particularly obnoxious for equipment movement, a layer of coal will be left in the floor. Regardless of the reason, some coal is left over the entire thickness area of the mine.

Support pillars are required by law in most states where subsidence could endanger permanent surface installations. In some locations there can amount to a sizable portion of the reserves. Recent failures under the residential area of Rock Springs, Wyoming display the value of such preparedness.

Specific percentage recovery of coal resources is very difficult to determine. Although figures are available from many sources [(5), (8), (13), (19)], the values assigned are derived on different basis. Just as production per man shift in quoted for face workers and the overall mine production is considerably less, recovery within a single panel or block of coal within a mine is usually high--as much as 90 percent in some cases. The recovery within the mine property boundaries is generally low. Across the U.S. underground mining has recovered about 55 percent of the coal developed (5, p. 29). The percentage applied to strip mining is 80% (8, p. 13).

The thicker seams minable in Montana permit higher percentage recoveries in strip mining since there is more coal per horizontal area. Although the cause of loss is equivalent to eastern operations,

Montana coal producers quote 95 to 98 percent recovery. This applies to coal within the mined pit. Coal is lost to spoil pile support ribs, spillage, mixing with loosened overburden and spoil slides. These reasons are acceptable and reasonable considering the increased cost of mining in manner to recover 100 percent.

In Montana, the Montana Strip Mining and Reclamation Act crosses the Coal Conservation Act by prohibiting mining within various areas of minable reserves. The 100 foot boundary band and the ability to deny access because of sundry surface phenomenon both reduce the recovered coal within an area. Within a given mining area in eastern Montana there will be probably recovery of resources between 90 and 95%.

Looking to the total strippable resource picture we can expect about 50% recovery. The reserves so far deliniated are based on limitations of overburden as a function of coal thickness. It is a simple matter to draw a given overburden thickness contour line and it is another matter to follow this line while mining. Strip mining methods and equipment are designed to mine in a strip. The name certainly is justified by the technique. It is very difficult if not impossible from an engineering viewpoint to design an economic operation that follows constant overburden meandering around the side of a butte or up the draw of a narrow drainage. Design parameters cause a cessation of equipment ability when a pre-determined overburden depth is reached. To function as intended, mining proceeds in orderly, straight or gently curving strips. When deep overburden is encountered, the strips stop irregardless of small, shallower areas beyond.

Social or political problems influence recovery. The complex ownership of surface and mineral rights has reduced the probability of high recovery of coal resources. Conflicting goals of state and federal legislators, elected officials, governmental agencies, industrial companies, organized groups and private citizens create a complex scene for companies interested in reserve exploitation. In the Decker-Birney study area the Bureau of Land Management and the Forest Service control 26 percent of the surface but 88 percent of the coal. State and private entities own 74 percent of the surface but only 12 percent of the coal. At Sarpy Creek the coal is controlled by the Crow Indians but the surface is privately owned. In other areas alternate sections are owned by the railroad and the surface may be owned privately. Since the state does not recognize the right of emminent domain for coal, a private concern can withhold areas and cause adjoining resources to be unminable. Decisions by an immature agency division has withdrawn areas in the midst of preconceived mining plans and caused resource loss. Although this is legal under law, the loss of energy resources must be recognized.

Should underground coal mining become a reality in Montana, recovery in seams of ten to fifteen feet should approach the higher percentages found in the eastern U.S. It is difficult to predict, however, since large scale underground mining has taken place in only a limited manner. Mining near Roundup recovered only about 50 percent of the coal. Examination of old maps indicates many areas of bad top. Underground mining of strippable reserves under shallow overburden has not been attempted with thick seams. Evidence of smaller mines indicates low recovery. The mining of thick seams under deep cover is

probably far in the future unless economic conditions or legislative proclamations change.

Coal recovery in preparation plants should have no effect on Montana coal. The purpose of coal washing is to remove sulfur and parting or roof contaminants. Loss of raw coal processed through preparation plants averaged 22 percent (8) but this also includes the refuse portion. For the underground mines the proportion cleaned is 72 percent as compared with 42 percent for surface mines (13). Coal is usually processed only enough to meet sales contract specifications. The foremost problem with Montana coal is the moisture content which runs about 25 percent.

Drying of Montana coal is the only process manipulation practiced at present. The drying is not done through plant facilities but as a matter of course through blasting, haulage, crushing and loading. Most coal shipped out of the state contains ten to fifteen percent moisture. Excess drying is detrimental to further handling and storage as sub-bituminous coals and lignite become extremely friable when dry and deteriate rapidly. Reducing the moisture content does increase Btu per ton and reduces shipping cost per Btu. Future contracts could require some thermal drying for closer control but this is doubtful. Losses in thermal drying are minimal particularly in view of requirements for dust control in plant areas. Recovery of coal from preparation plants in Montana should be no problem.

Markets for Montana Coal

The markets for Montana Coal appear uncountable. In five years our resources have developed into vast reserves. How, in such a short time has this happened? In reality a combination of legislative acts and industrial enterprise merged with a growing awareness of future energy requirements to open the west as a coal producing area.

Legislation of acts requiring lower levels of stack emissions, particularly sulfur compounds, created a need for low sulfur coal. Industrial enterprise represented by railroads willing to create low ton-mile cost unit trains and by mining companies with the capital and knowledge required to open new mines in undeveloped areas supplied the consumable energy resource product. If the scene had ended at this point, concern for the effects of coal development in Montana would be minimal. However, hard on the heels of the initial efforts came the stark awareness of a possible energy shortage or at best a crisis of supply.

This last measure has prolonged the interest until an accounting of considerable magnitude is desirable. To predict the market for Montana coal is very difficult. Many problems hinder development, ranging from physical to political. Some might even question the urgency of development. The dynamic growth experienced, and expected in the immediate future, is a function of the first two factors mentioned. Long term growth is more a function of the final factor, total energy demand of the United States. Should economically attractive means of capturing sulfur dioxide emissions come about, the market for Montana coal could become very static. Simple,

high volume antipollution systems have high priority in many plant development companies. For example, a "second generation" scubber system has been developed which will satisfactorily clean 3 percent sulfur. Cost is estimated at 25 cents per million Btu and a salable byproduct should reduce the overall cost (26). This is $6.00 per ton of high Btu coal but represents the possibility and concept that low sulfur coals have a limited economic demand. Montana coal has a low sulfur market only as long as it can compete economically with high sulfur emission control devices. The capital required to develop coal reserves in Montana must look to this possibility before investment.

Long term development is yet more difficult to predict as only minute production of coal based gas or liquid hydro-carbons has been developed. Many companies and federal research agencies are preparing for eventualities but hard commitments for plant installations are few. Montana coal resources are desirable in the long term picture but not more so than other western states.

Montana's coal market does have a firm base as an energy source for electricity generation. Future requirements of the west coast metropolitan centers indicate continuing and expanding market for Montana coal particularly if the energy can be shipped by wire. Dramatic expansion of demand is a function of real natural gas and oil reserves. Should gasification or liquefaction become very competitive, Montana coal is one of the resource areas of interest. It must be comparable on an economic basis, particularly as concerns taxation and mine reclamation. Desirable physical and chemical attributes are not unique enough to sell Montana coal.

Steam Coal Market

Montana coal resources fit well into the pattern of a conventional energy source for steam-electric power plants. The low Btu content is offset by lower than average sulfur content. Conventional markets represent the core of the Montana coal industry at present. The following information annotates the present and recognized predicted production in this area of coal usage.

Knife River has a fixed production of 320,000 tons per year to the power plant at Savage, Montana. Peabody's Mine produces two million tons for Minnesota Power and Light. Westmoreland Resources at Sarpy Creek has begun shipments of 4 million tons per year to four midwest utilities. Decker Coal Co. will ship 4 million tons per year each to Commonwealth Edison and Detroit Edison. The Detroit Edison contract will expand to 7 million tons per year by 1981. The Colstrip operation of Western Energy will ship 2.3 million tons per year to Wisconsin Power and Light by 1975 and in the same year begin supplying 3 million tons per year to Montana Power plants at Colstrip. Smaller productions of 0.5 million tons and 0.4 million respectively go to the Corette plant in Billings and to Northern States Power.

Thus production of coal by surface mining in Montana will total 20 million tons in 1975 and go to at least 23 million by 1981. If approval is gained for the two new 700 megawatt plants at Colstrip, 1981 production can jump another 6 million tons and reach about 30 million tons per year. A proposed 1200 megawatt power plant of Basin Electric Power is yet in the discussion stage. A recent announcement indicates it will be built in Wyoming rather than Montana.

Coal Conversion Market

The preceding discussed existing or proven markets for Montana Coal as that used for electrical generation. More nebulous markets exist in the area of coal gasification and liquefaction. Westmoreland at Sarpy Creek has reserved 300 million tons for possible use in this area. Much of the reserves on Indian land were dedicated to such use also but recent moves to cancel existing contracts has clouded development. Irregardless, the gasification market may or may not exist. To date, no large scale gasification plants are producing and no hard plans have been filed within the state. To proscribe or eagerly anticipate such existence in the immediate future is a moot topic. Montana coal does fit many of the projected requirements for gasification however.

Coal gasification requires what Montana resources offer, not only from physical and chemical properties but by sheer volume. One unalterable fact appears that a 250 million cubic feet per day is the minimum economic size for a gasification plant. To supply such a plant, Montana coal at 8500 to 9000 Btu per pound would be mined at a rate of 9.5 to 9 million tons per year. This figure would be one fourth of Montana's 1981 coal production and represents only one plant. In 1972 only 10 mines produced in excess of four million tons (22). Resource input would be required from multiple sources or at least multiple working places within a single area. One plant of this type with a 30 year life would expire the total reserves set aside by Westmoreland Resources near Hardin for just such a project.

The requirement of a large block of committed coal is only attainable in the west. Although the reserves exist in the midwest, the continuity attainable defies an economic installation for gasification. Only a few plants of minimal size would create haulage problems unless the plant is sited at the source.

Water is another of Montana's resources that enter into coal use at this stage. A 250 million cubic feet per day gasification plant requires 20 to 30 thousand acre feet of water per year. This is not a tremendous amount in itself as agricultural usage is over one million acre feet per year in the Yellowstone basin. Concern over water consumption for the two 350 megawatt generators at Colstrip indicates the social and political innuendos associated with industrial water use in Montana.

Unless natural gas supplies become severly restricted, Montana will probably not be inundated by gasification plants. Preliminary work on siting is underway in North Dakota and New Mexico however. North Dakota lignite appears very ameanable by location and Btu value for gasification. Montana may expect continued interest in this field of resource utilization and undoubtedly will have coal gasification plants in the future. The probability of Montana acquiring one of the first installations is slim. Reasons for slower development are detailed in the next section.

Underground gasification is another outlet for the coal resources of Montana. Although present research in Wyoming (23) taps relatively shallow coal, the best implimentation would be in the deeper, thick seams. In situ gasification as yet is only a research concept. Low Btu gas is the product and the controlled burning

required for consistent generation is not well in hand. A similar endeavor by the AEC would pump steam and oxygen underground thus removing the difficult underground burning and produce a natural gas. Limitations and economics of producing oxygen and steam for injection create their own environmental problems with associated energy consumption. Previous attempts at in situ work have indicated low resource recovery.

Coal liquefaction represents a potential market for Montana coal. A plant comparable in Btu to the gas plant previously discussed would produce 25,000 barrels per day (assuming low Btu gas) and consume a similar quantity of coal and water. The Office of Coal Research (24) is particularly interested in liquefaction for the following reasons:

1. Energy conversion of about 78% in liquefaction versus 60% at best in gasification.

2. Liquefaction plants can come on line sooner since lower operating temperatures use conventional equipment.

3. Oil is more cheaply stored and transported than gas on a Btu basis.

4. Environmental control is cheaper.

Transportation

Regardless of the coal consumption mechanism that creates the market, Montana coal has transportation problems. If the coal is shipped raw out of state, rail transportation and unit trains are the primary solution. Much of Montana's main line haulage which surrounds the northern, western and part of the southern limits of south eastern Montana, is only single track with long turnouts. The vast reserves deliniated by the Montana Bureau of Mines and Geology

are virtually untapped by rail access. twenty mile spur into Decker and a thirty mile spur into Sarpy Creek and Colstrip represent marginal encroachments into a large area. More than 80 miles of rail would be needed to connect these fingers. Over 100 miles is necessary to finish the old right-of-way along the Tongue River to Miles City and these would only split the area into two segments. At one quarter of a million dollars per mile rail develop needed to exploit Montana's coal is an expensive proposition.

Another method of energy shipment is by electrical transmission and this again is virtually undeveloped. In-state coal burning and electrical generation has encountered much opposition, even from elected officials (25). Transmission lines seem to be considered ecological eyesores and no decision has been made on Montana Power's new, proposed line. In any event, to utilize this mode of energy transfer, new facilities are required for development of coal reserves.

Slurry pipeline transportation of coal is another possibility. The idea is yet in the planning stages but has been proven feasible for over 100 miles ten years ago in Ohio. Problem areas exist physically in product degradation, particularly weak, sub-bituminous coals over long distances. Political and legal problems of interstate water movement in agriculturally dominate states changes the perspective of this mode of transportation. Wyoming has recently authorized 20,000 acre-feet of ground water for such a pipeline.

The Montana market for our abundant energy source, coal, is not large. Nearly all of the potential market is out of state and transportation is a limiting factor for the growth or rate of growth

of the coal industry here. The cost of rail haulage and or energy conversion and transmission represent one control on the competitiveness and hence the marketability of Montana Coal. Freight rates to some eastern markets are more than triple the mine mouth value of the coal. Transportation then is one of the major controls on the market position of Montana coal.

Figure 15 represents the growth and projection of Montana coal use from 1969 when development began until 1985, a predictable future. The projections are conservative but are based on realistic examination of fact. Montana has had no new mine applications since the 1973 Strip Mine Reclamation Act went into effect and the more exotic markets of gasification and liquefaction are not a reality commercially.

Favorable conditions of growth assume: Montana tax burdens on coal production are equitable with surrounding states; reclamation is reasonably enforced and long range planning is feasible; government sulfur emissions are enforced and no low cost emission control equipment becomes available; and the apparent energy crisis is solved using coal.

A static condition will exist if: adverse strip mining conditions are enacted; other energy sources such as oil shale or nuclear develop quickly; or high sulfur coal becomes acceptable as an energy source. Predictions are difficult after examining these alternatives. Undoubtedly the market for Montana coal will grow, the question is at what rate?

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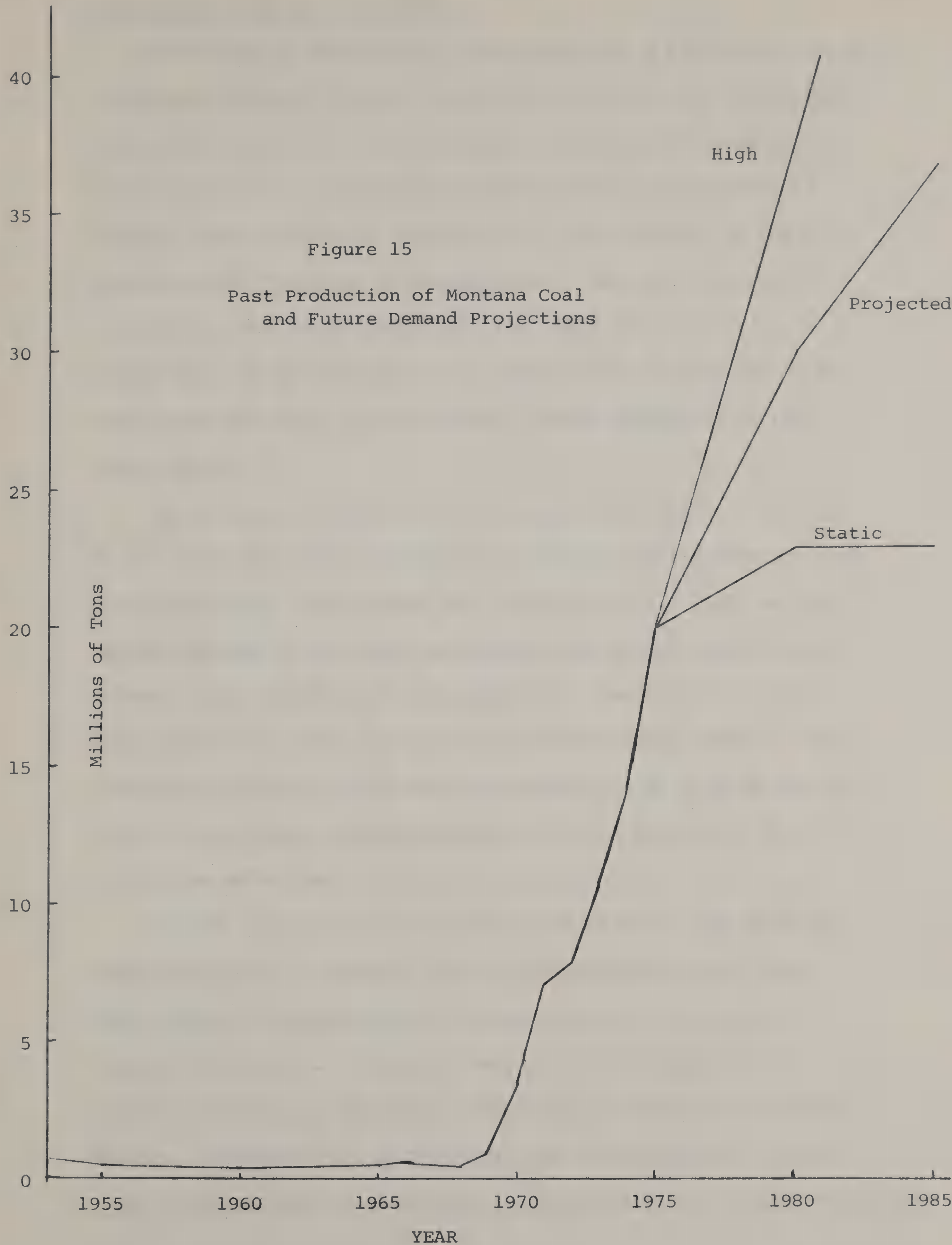

Figure 15

Past Production of Montana Coal and Future Demand Projections

Montana Coal Regulatory Actions

Regulation of Montana coal mining has over a fifty year history beginning with the 1921 coal tax of five cents per ton. Although not a true regulation, this separate tax represented state government recognition of a consumable resource and the initiation of control. The most recent culmination of state control is the Montana Strip Mining and Reclamation Act. This Act with others such as the Coal Conservation Act, the Strip Mine Siting Act, and existing or proposed levels of taxation has created one of the most formidable state controlled coal mining industries in the United States.

The effect on industry of Montana coal regulation is apparent. No new mines have been developed nor have any applications for such been filed since the Act went into effect in 1973. Those on the boards previous to then have gone ahead, but no new efforts have arisen. While adjoining states have been expanding their industrial and mining base, Montana coal development has stopped. Some exploration programs and lease developments are in progress but in view of the stream of announcements from North Dakota and Wyoming, Montana has effectively squelched coal development.

Montana coal is certainly competitive from its natural attributes.therefore the reasons for logging development must have other cause. The existence of thorough state control is not intolerable in fact. It is the fancy of jurisdiction that the mining industry must see before expanding development by expending dollars. Some sections of the mining and reclamation act are too loose to entice capital which must be depreciated over long time periods.

The decision making and enforcement of other sections has not enough precedence to offer a well structured policy for mine development. Taxation is still in a state of flux and proposed levels could reduce the economic competitiveness of Montana Coal considerably. Assuming the major portions of the Montana Strip Mining and Reclamation Act are acceptable to industry, what parts make them hesitant?

Section six of the act rules on the acquisition of an annual permit required by any operator engaged in strip mining and sections nine and thirteen expand on denial provisions of this permit. The general nature by which the denial causes are stated allows great latitude by the enforcing agency. Companies are hesitant to invest great amounts of capital such as detailed in Appendix B, when there exists an annual possibility of closure and loss of the investment. This has never occurred but the fact that such action could take place motivates companies to invest their capital under safer conditions in other states.

Other problem areas exist in the application of the intent of the act. Section 9-(2) denies mining where the land may have "special, exceptional critical, or unique characteristics" and where mining might adversely affect the use of character of that or neighboring land of similar quality. Various specifics are then listed with ecological fragility and scenic, topographic or geological significance popular as reasons for denial of mining. These reasons have been applied as valid denials already.

It is important to realize that the preservation of an isolated block can cause loss of coal recovery in areas adjacent. Strip mining is by design a repetition of long slices and interruption

of the series causes spoil handling problems which lead to high cost coal and low resource recovery. While the same agency prohibits mining in one area it enforces mining in another through the Coal Conservation Act. Unless close accounting is maintained one act may easily overwhelm the other.

Section 26-2.10(10) - S10340 of the rules and regulations adopted pursuant to the Act covers topsoiling. Sub-section one of this states that "all available topsoil shall be removed---". The deliniation of topsoil is a delicate topic and difficult to put hard numbers on. As shown later in this part of the report, any excess definition of topsoil depth can increase reclamation costs rapidly.

Section 26-2.10(10) - S10310 deals with mining and reclamation plans and becomes rather specific in some sub-section. Sub-section 4(A) allows haulageway roads only when "their presence does not delay or prevent recontouring and revegetation on immediately adjacent spoils". Engineers go to great effort to design permanent haulageways since continuous development of new roads is expensive both in construction and in production bottlenecks. Over zealous enforcement here belies the intent which is probably to stop willful delay of reclamation. The following parts of this section, covering ramp roads and access roads is very specific compared to the tone of the majority of the regulations. The reason for this is not exactly clear and the limitations inhibit engineering design to a degree.

In any event, the credibility of enforcement and interpretation of the meaning of the Act is critical to development of Montana coal.

Antagonistic application of the Act will keep industry out of Montana just as ambivalent acquiescence will reduce the intent. A well rounded enforcement agency is necessary to provide the diverse skills required to evaluate problem areas in an unbiased manner.

The Strip Mined Coal Conservation Act is another act of good intent but potential conflict. The prevention of obvious waste is the concept but conflicts in defining marketable or minable coal are inevitable. In a high production operation recovery of small percentages of rib coal can be a high cost "saving". Rib coal left to support the spoil pile is difficult to define as waste. Increased safety from such support can be invaluable. The rib can produce increased equipment production through decreased reach requirements and wider, safer pits. Wasted coal and increased production are very tenuous subjects to relate. In these times of high equipment demand and slow deliveries, high recovery can be counter to contract production capabilities.

Montana Reclamation

An operator of a coal strip mine in Montana must meet the requirements of the Montana Strip Mine and Reclamation Act. The operator is required to return the land to its approximate original contour and must establish vegetation capable of withstanding graying pressure from livestock and wildlife comparable before mining. The vegetation must be capable of regenerating under natural conditions. Failure to meet these and other specific rules can result in civil penalties or misdemeanor action and revocation of the mining permit.

Reclamation consists of three steps, topsoil removal and replacement, grading of spoils, and finally, revegetation. Topsoil handling is a costly event and the definition of topsoil depth can influence reclamation costs highly. Every 6 inches of topsoil creates 807 bank yards per acre to be moved. With 20% swell, 968 loose cubic yards must be handled.

Costs for scraper handling of topsoil run about 25 cents per yard. Since the soil must be stock piled and then rehandled after mining a total of 50 cents per yard is accrued in handling. This amounts to $484 per acre disturbed for each six inch slice of topsoil. Recent rulings have specified slightly less than two feet of overburden designated as topsoil. Topsoil handling would then run between $1500 to $2000 per acre. Above this cost is the temporary seeding of the stock piled soil as required by law. Tests have indicated that the poor quality of surface material will not sustain growth in a manner superior to some of the general overburden, encountered in mining. The definition and emphasis placed on topsoil is critical to the economic viability of Montana coal and recognition of this by the ruling agency is a must.

Grading of spoils to approximate original contour and reduction of all slopes to less than 5:1 as required is another source of reclamation expense. Figure 16 shows the cubic yards of material to be handled for various degrees of spoil reduction. A one hundred foot wide pit is assured. Since much of this can be dozed, handling costs are less than for scrapers. At ten cents per yard, restoration of original contour and slope flattening would be a minimum of $600 per acre to an average maximum of $1000 per

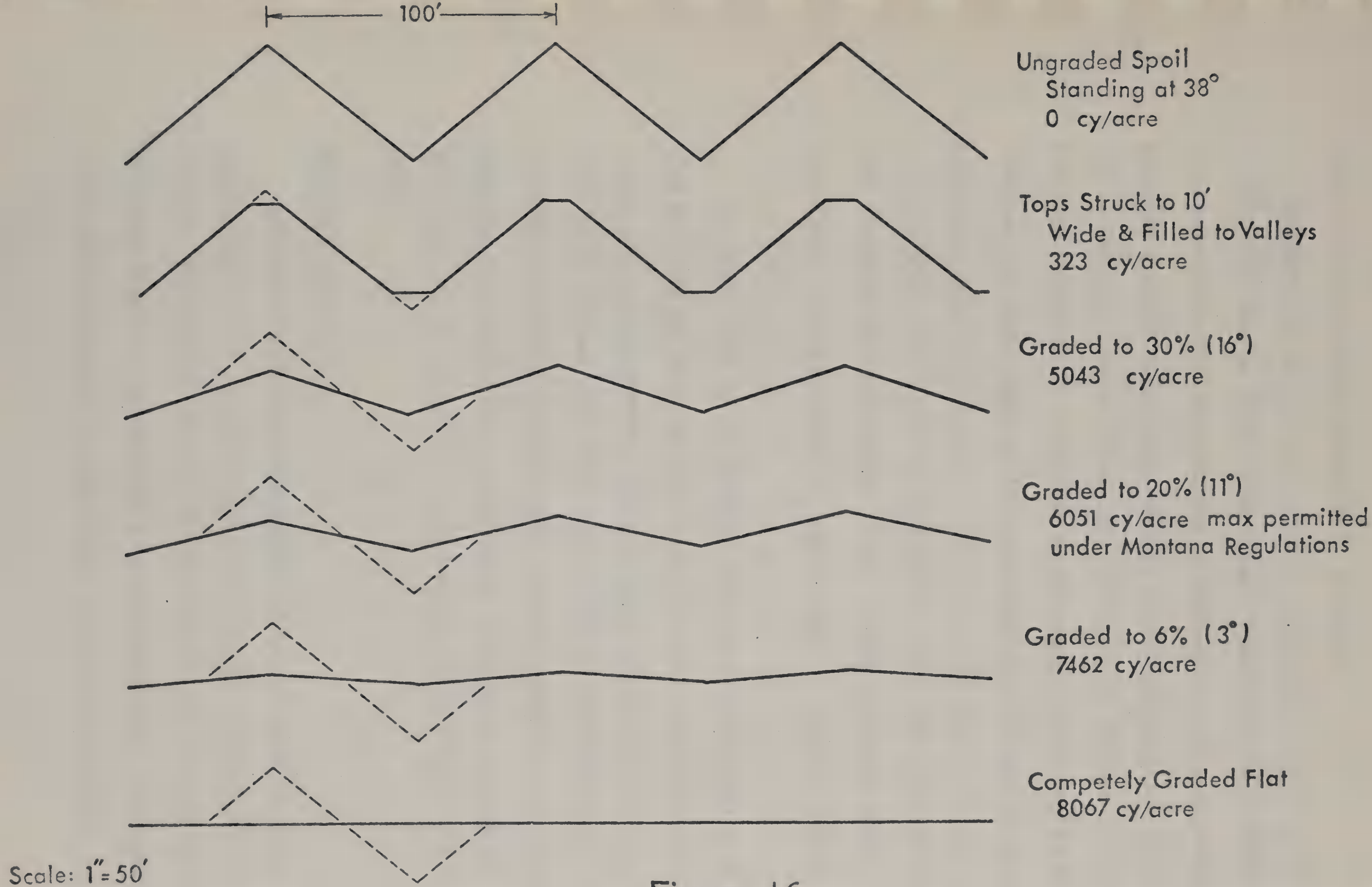

Figure 16.

Reduction of Spoils Peaks
By Varying Degrees

acre if final highwall reduction is included.

Revegetation is the final cost of reclamation and is difficult to deliniate from an engineering view. Despite emotional reports by conservationists, revegetation is succeeding (27) and growth will probably respond better than original. Much experimental work has and is working. The original data available for Montana was non-existent and progress to date is exceptional. Irrigation is not required and three years of fertilization is sufficient to introduce self sustaining organic base to the soil. The cost of revegetation includes seed, fertilizer and primarily labor. If research costs were included in these initial years, the per acre cost would skyrocket. A good estimate of revegetation in the long run is $100 to $200 per acre.

The total cost of reclamation could be as low as $1100 or as high as $3200 per acre if deep topsoil removal and difficult original contouring is encountered. Neither price reflects the quality of reclamation but more the total quantity of handled material. Good reclamation is worth the investment and the results of short time experience are gratifying. Reclamation costs under reasonable guidelines should not effect the economic competitiveness of Montana coal.

Montana Coal Tax

Although not strictly regulatory in nature, special taxes on coal effect to a high degree the future of coal development in Montana. For Montana coal to be competitive with production from adjoining states, a comparative taxation must exist. The energy crisis would apparently reduce some of the economic aspects and

emphasize the production capabilities of a mine. This does not seem the case as coal contract bids remain highly competitive. Reportedly, contracts have been lost to operations in Wyoming where taxes are less.

Montana taxes coal in four ways. The Mining License Tax is based on the Btu value of the coal mined and the specific amounts are shown below:

Btu	¢/ton
7,000 or less	12
7,000 to 8,000	22
8,000 to 9,000	34
9,000 or more	40

There is an additional Resources Indemnity Trust Fund Tax which is to be used as a trust fund for reclamation of land where the operator has defaulted or for reclaiming old land. The tax amounts to 1/2 of 1 percent of the sales price.

The third tax is a property tax which is a county based tax. The 1973 Big Horn County Tax was 15.3 percent of the taxable value. The taxable value varies but in Big Horn County is calculated as a sum of classes taxed on a 40 percent base of the true value. As an example, class 4 includes real estate and improvements and manufacturing or mining machinery. The rate is 30 percent of the 40 percent base or 12 percent of the real value.

The final tax is the Net Proceeds of Mines Tax. The net proceeds of the mine are made up of the gross revenue less royalties, direct costs of mining, some depreciation based on assessed value and some administrative expenses. The net proceeds are taxed at the county property tax rate as above.

The reported taxes will amount to 27 cents per ton for the lignite mined by Knife River to a high of 74 cents per ton for Decker. Wyoming, our closest competitor for sub-bituminous production has only a severence tax and a gross production tax. The difference per ton is considerable as a typical tax in Wyoming totals only 15 cents per ton.

In the last legislative meeting in Montana an attempt was made to change the license tax to a flat 16 percent of the price paid for delivered coal by the consumer. This was defeated but hearings will soon be held to discuss a new report by the Joint Interim Subcommittee on Fossil Fuel Taxation. Obviously more changes are possible.

Other taxes include the 6 3/4 percent corporate license tax and prospecting permits or tax. The most undesirable feature of all the taxes is the Net Proceeds of Mines Tax explained previously. None of the state taxes are deductible in calculating this. The sales price upon which the net proceeds are calculated includes consideration of state taxes and hence the county tax is a form of double tax.

Taxation is a critical element in determining the market position of Montana coal. Presently, Montana has a high base compared with adjoining states thus controlling development to an extent. Minnesota solved the tacomite tax problems with a general referendum. In states with low population, the tendency to overtax the few industries operating is predominent. Careful examination is required to honestly determine tax levels.

Conclusion

The rapid rise of industry interest in Montana coal has created equal interest by the State of Montana and by private citizen groups. Both desire orderly development but over reaction of legislative groups and by enforcement agencies has apparently created a no growth atmosphere for coal development. In fact, no new mines have been developed since the 1973 legislative acts became effective. Synthesis of development goals within the state must be reviewed and regulation adjusted accordingly. As long as adjoining states are more cordial to mining, Montana development will not expand.

Strip mining of coal in Montana is a very sensitive operation. Competition for land to supply soil and water for agricultural purposes, recreation, and industry is intense. Tradition and social values are competing with dollars of industrial production. Land that supports one cow for every thirty acres can produce $330,000 in royalties from 25 feet thick coal. Mining of depleatable resources is a temporary thing but political opinion controls development.

Use of Montana coal as an energy resource is very feasible. Montana has the quantity of reserves that can be developed to a high degree. Underground mining is physically possible but economically unsound. Coal mined underground at $9 a ton and shipped east for another $9 per ton cannot compete with $4.50 a ton coal from the midwest that can be shipped for $3 per ton. Subsidence from mining thick seams can be more difficult to reclaim than from surface mining where reclamation parameters are well in hand. Safety in surface mining is better than underground.

High production per man in surface mining limits the problems of population influx that could occur with underground mines. The technical problems of trained personnel and equipment supply to develop underground mines indicate that rapid development in this area is improbable.

Montana coal suffers remote location from markets, transportation costs, low Btu value, and competition from other energy sources. While desirable from the viewpoint of mining costs and reserve volumes, Montana alone does not have the only resources with these characteristics. Development is probable but only under favorable control attitudes. Opposing coal interests must avail themselves to an open interchange of ideas if satisfactory development is to continue.

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TABLE D-1. - Capital investment summary, 4.99 MM tpy mine

Item	Quantity	Total cost
Continuous miner	26	$6,273,800
Loading machine	26	1,677,000
Shuttle car	52	3,083,600
Roof bolter	26	1,107,600
Ratio feeder	26	936,000
Auxiliary fan	26	78,000
Mantrip Jeep	26	364,000
Mechanic Jeep	10	110,000
Personnel Jeep	10	100,000
Trickle rock duster	26	91,000
Triple duty rock duster	15	465,000
Supply motor	8	200,000
Supply car	100	250,000
42-inch rope type mainline belt conveyor	9,000 ft	576,000
36-inch rope type secondary and panel belts	60,000 ft	3,303,500
Mainline belt power center (300 kV-A)	6	90,000
Section belt power center (150 kV-A)	16	160,000
Section power center (1,000 kV-A)	26	598,000
Section rectifier (200 kW)	26	52,000
Section switch house	26	195,000
Sectionalizing switch house	12	90,000
HV cable (300 MCM AL)	21,000 ft	168,000
PLM coupler	22	17,200
Section cable and coupler		109,200
Rectifier for truck haulage	5	100,000
Trolley wire	69,000 ft	172,500
Track (60-lb)	69,000 ft	552,000
Fresh water line	69,000 ft	207,000
Pumps and lines		35,000
Telephone (page phones)		14,000
Conveyor fire protection		30,000
Automatic controls and alarms		100,000
Scoop tractor	26	650,000
Battery charger	26	52,000
All service mask	36	3,600
Breathing apparatus	50	31,300
Self rescuer	950	28,500
Stretcher set	40	5,000
Safety light	600	21,000
Methanometer	600	180,000
Fire chemical car	15	45,000
Lamp (including accessories)	950	39,900
Dust sampler	75	22,500
Site preparation		60,000
Ventilation fan (dual)		92,000
Concrete portal	5	70,000
Bulk rock dust facility	1	45,000
Substation and distribution	1	88,000
Bathhouse, office, and lamp house	1	550,000

TABLE D-1. - Capital investment summary, 4.99 MM tpy mine - Continued

Item	Quantity	Total cost
Shop and warehouse..................	1	350,000
Powder and cap house................	1	9,000
Front-end loader....................	1	50,000
Forklift............................	1	20,000
Bulldozer...........................	1	80,000
Utility truck.......................	2	8,000
Pickup truck........................	3	9,000
Oil storage.........................	1	30,000
Water tank..........................	1	20,000
Supply yard.........................	1	20,000
Mine drainage treatment plant.........		30,000
Exploration.........................		250,000
Total direct....................................		24,165,200
Field indirect..................................		483,300
Total construction..............................		24,648,500
Engineering.....................................		493,000
Overhead and administration.....................		1,257,100
		26,398,600
Contingency.....................................		3,959,800
		30,358,400
Fee...		607,200
		30,965,600
Estimated development cost......................		19,089,900
		50,055,500
Interest during development.....................		1,501,700
Gross estimate..................................		51,557,200
Credit for coal mined during development at $6.50 per ton		19,843,200
		31,714,000
Land acquired at $350 per acre..................		5,679,800
Net estimate....................................		37,393,800

TABLE D-2. - Manning table, 4.99 MM tpy mine

Personnel	Total	Wages[1] per day	Annual cost, 220 workdays
Underground			
Continuous miner operator.	66	$50.00	$735,680
Loading machine operator..	66	47.25	695,750
Machine operator helper...	66	47.25	695,750
Shuttle car operator......	132	43.25	1,275,340
Roof bolter..............	132	47.25	1,391,500
Bratticeman..............	66	42.75	630,410
Utility man..............	66	44.75	657,450
Mechanic (section)........	66	50.00	735,680
	660		6,817,560 or $1.36 per ton
Supply motorman..........	24	43.25	231,880
Beltman..................	45	42.75	429,825
Trackman.................	18	42.75	171,930
Wireman..................	18	42.75	171,930
Mason (precision).........	30	44.75	299,750
Pumper...................	6	42.75	57,310
Utility crew.............	36	44.75	359,700
Roving mechanic..........	18	50.00	200,640
	195		1,922,965 or $0.39 per ton
Outside			
Lampman..................	6	43.50	58,300
Front-end loader.........	3	43.50	29,150
Shop mechanic............	18	50.00	200,640
	27		288,090 or $0.06 per ton
Salary			
Superintendent...........	1		26,400
Assistant superintendent..	2		37,200
General mine foreman......	2		34,800
Assistant mine foreman....	3		43,200
Section foreman..........	66		831,600
Maintenance superintendent	1		19,800
General shop foreman......	2		27,600
Mine maintenance foreman..	3		41,400
Chief mine engineer.......	1		20,400
Draftsman................	2		16,800
Survey crew..............	6		54,000
Safety director..........	1		18,000
Safety inspector.........	3		39,600
Dust sampler.............	6		57,600
Office manager...........	1		14,400
Timekeeper and bookkeeper.	2		20,000
Purchasing supervisor.....	1		14,400
Warehouseman.............	6		54,000
	109		1,371,200 or $0.27 per ton
Total labor and supervision.....	991		10,399,800 or $2.08 per ton

[1]Figures in this column are for the day shift. Shift differentials for other shifts are reflected in the final column. Rates used are effective Nov. 12, 1973, under the Bituminous Wage Agreement of 1971.

TABLE D-3. - Depreciation schedule, 4.99 MM tpy mine

Item	Straight-line depreciation, years	Yearly charge, dollars
Exploration........................	20	12,500
Mine drainage treatment plant......	10	3,000
Supply yard........................	10	2,000
Water tank.........................	10	2,000
Oil storage........................	10	3,000
Pickup truck.......................	5	1,800
Utility truck......................	5	1,600
Bulldozer..........................	10	8,000
Forklift...........................	10	2,000
Front-end loader...................	10	5,000
Powder and cap house...............	10	900
Shop and warehouse.................	20	17,500
Bathhouse, office, and lamp house..	20	27,500
Substation.........................	20	4,400
Bulk rock dust facility............	10	4,500
Concrete portals...................	20	3,500
Ventilation fan....................	20	4,600
Site preparation...................	20	3,000
Coal mine safety equipment.........	5	93,400
Underground equipment..............	10	2,191,700
Interim equipment replacement......	20	365,000
Subtotal.....................		2,756,900
Depreciation for field indirect, engineering, overhead and administration, contingency, fee, cost of development, and interest during development, less credit for coal mined at $6.50 per ton................	20	377,400
Total........................		3,134,300 or $0.63 per ton

TABLE D-4. - Power and water cost, 4.99 MM tpy mine

Number of units	Operation	Hp per unit	Hp, total load	Hr per day, full load	KW, total load	Total kWhr requirement
22	Continuous miner..	600	13,200	15	9,847	147,705
22	Loading machine...	160	3,520	15	2,626	39,390
44	Shuttle car.......	135	5,940	15	4,431	66,465
22	Roof bolter.......	50	1,100	18	821	14,778
22	Ratio feeder......	125	2,750	15	2,052	30,780
22	Auxiliary fan.....	30	660	18	492	8,856
22	Mantrip Jeep......	15	330	6	246	1,476
10	Mechanic Jeep.....	15	150	15	112	1,680
10	Personnel Jeep....	7.5	75	15	56	840
22	Rock duster.......	30	660	12	492	5,904
8	Supply motor......	80	640	12	477	5,724
3	42-inch conveyor..	300	900	15	671	10,065
20	36-inch conveyor..	150	1,200	15	895	13,425
1	Ventilation fan...		500	24	373	8,952
	Extra for pumps, tools, lights, etc.............		700	10	522	5,220
	Total......................................					361,260

Power: \$0.01 x 361,260 x 220 = 794,800 ÷ 4,994,900 = \$0.16 per ton
Water: 3,000 gal per unit per shift at \$0.10 per M gal
= 3,000 x 22 x 3 x 220 x 0.10 ÷ 1,000 = \$4,400

TABLE D-5. - Estimated annual production cost, 4.99 MM tpy mine

	Annual cost	Cost per ton
Direct cost		
Production:		
Labor	$7,891,600	$1.58
Supervision	1,282,400	0.25
	9,174,000	1.83
Maintenance:		
Labor	1,137,000	0.23
Supervision	88,800	.02
	1,225,800	.25
Operating supplies:		
Mining machine parts	2,497,500	.50
Lubrication and hydraulic oil	999,000	.20
Roof bolts and timber	1,248,700	.25
Rock dust	499,500	.10
Ventilation	749,200	.15
Bits	399,600	.08
Cables	249,700	.05
Miscellaneous	499,500	.10
	7,142,700	1.43
Power	794,800	.16
Water	4,400	
Payroll overhead (35 percent of payroll)	3,639,900	.73
Union welfare[1]	3,746,200	.75
Indirect cost		
15 percent labor, supervision, and supplies	2,631,400	.53
Fixed cost		
Taxes and insurance, 2 percent of mine cost	717,800	.14
Depreciation	3,134,300	.63
	3,852,100	.77
Total	32,211,300	6.45

[1]Effective Nov. 12, 1973, under the Bituminous Wage Agreement of 1971.

TABLE D-6. - Estimated development cost[1], 4.99 MM tpy mine

Item	Total cost	Cost per ton
Total labor and supervision...........	$7,832,000	$2.56
Operating supplies....................	2,747,500	0.90
Power.................................	366,300	.12
Payroll overhead......................	2,741,200	.90
Union welfare.........................	2,289,600	.75
Indirect cost.........................	1,586,900	.52
Fixed cost............................	1,526,400	.50
Total.........................	19,089,900	6.25

Cost per ton = $6.25
Tonnage = 3,052,800
Credit for coal mined at $6.50 per ton = $19,843,200

[1]Estimated development cost covers the period of time required to place all units in operation within the projected mining plan.

TABLE D-7. - Estimated working capital and total capital investment, 4.99 MM tpy mine

Estimated working capital	
Direct labor...............................3 months...	$2,599,900
Operating supplies.........................3 months...	1,785,700
Payroll overhead...........................3 months...	910,000
Indirect cost..............................4 months...	877,100
Fixed cost............0.5 percent of insurance base...	179,500
Spare parts...	874,500
Miscellaneous...	100,000
Total working capital............................	7,326,700
Total estimated capital investment	
Total mine cost (insurance, tax base).................	35,892,100
Interest during development...........................	1,501,700
Subtotal...	37,393,800
Working capital.......................................	7,326,700
Estimated capital investment.....................	44,720,500
Estimated deferred capital investment.................	30,973,000
Total capital investment and deferred investment....	75,693,500[1]

[1] This is an average cost of $15.15 per ton of annual production.

TABLE D-8. - Summary of discounted cash flow, 4.99 MM tpy mine

Year	Capital investment	Cash flow	Present worth factor at 12 percent	Present worth capital investment at 12 percent	Present worth cash flow value at 12 percent
0	$44,720,500	$-44,720,500	1.	$44,720,500	$-44,720,500
1	365,000	6,834,400	0.8929	325,900	6,102,400
2	365,000	6,834,400	.7972	291,000	5,448,400
3	365,000	6,834,400	.7118	259,800	4,864,700
4	365,000	6,834,400	.6355	232,000	4,343,300
5	849,000	6,350,400	.5674	481,700	3,603,200
6	365,000	6,834,400	.5066	184,900	3,462,300
7	365,000	6,834,400	.4523	165,100	3,091,200
8	365,000	6,834,400	.4039	147,400	2,760,400
9	365,000	6,834,400	.3606	131,600	2,464,500
10	23,070,000	-15,870,600	.3220	7,428,500	-5,110,300
11	365,000	6,834,400	.2875	104,900	1,964,900
12	365,000	6,834,400	.2567	93,700	1,754,400
13	365,000	6,834,400	.2292	83,700	1,566,400
14	365,000	6,834,400	.2046	74,700	1,398,300
15	849,000	6,350,400	.1827	155,100	1,160,200
16	365,000	6,834,400	.1631	59,500	1,114,700
17	365,000	6,834,400	.1456	53,100	995,100
18	365,000	6,834,400	.1300	47,500	888,500
19	365,000	6,834,400	.1161	42,400	793,500
20	-12,641,500	19,840,900	.1037	-1,310,900	2,057,500
				53,772,100	3,100

TABLE D-9. - Discounted cash flow, 4.99 MM tpy mine

12 percent - 20 years

R = 53,772,100 ÷ 7.469[1] = $7,199,400
less depreciation 3,134,300
Depletion + net profit = 4,065,100

Gross profit = FIT + depletion + net profit
Depletion = 1/2 gross profit
FIT = net profit
Depletion + net profit = 3/4 gross profit
Gross profit = 4/3 x 4,065,100 = $5,420,100

Sales..............	$37,631,400
Operating cost.....	32,211,300
Gross profit.......	5,420,100
Depletion..........	2,710,100
Taxable income.....	2,710,000
FIT................	1,355,000
Net profit.........	1,355,000

Annual cash flow = net profit + depreciation + depletion
= 1,355,000 + 3,134,300 + 2,710,100 = $7,199,400

Selling price per ton = $37,631,400 ÷ 4,994,900 = $7.53

[1] Uniform series present worth factor.

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APPENDIX B

5 MILLION TON/YEAR SURFACE MINE

TABLE 61. - Equipment cost summary (Montana)

Item	No.	Unit cost	Total cost
Drills, overburden...........................	4	$149,000	$596,000
Drills, coal.................................	2	14,400	28,800
Explosives truck.............................	1	23,400	23,400
Dragline (including freight and erection)......	1	5,782,000	5,782,000
Front-end wheel loaders, coal.................	2	129,000	258,000
Haulers, coal (bottom dump)....................	4	119,300	477,200
Supply truck.................................	1	6,000	6,000
Sprinkler truck..............................	1	32,000	32,000
Service truck (gas and oil)..................	1	30,000	30,000
Mechanics truck..............................	1	6,000	6,000
Welding truck................................	1	8,000	8,000
Pickup trucks................................	6	3,500	21,000
Utility lift truck...........................	1	24,000	24,000
Electrician truck............................	1	5,000	5,000
Scrapers.....................................	2	157,800	315,600
Motor grader.................................	1	69,600	69,600
Dozers.......................................	3	103,000	309,000
Rippers, hydraulic for dozers................	2	11,700	23,400
Pumps, sump..................................	2	5,000	10,000
Towers, floodlight...........................	10	1,800	18,000
Automobiles..................................	2	3,800	7,600
Carryalls, personnel.........................	2	4,500	9,000
Substation, power............................	-	-	50,000
Transmission line, power (initial installation)	-	-	15,000
Unit-train loading facility..................	-	-	1,000,000
Pump, casing and well........................	-	-	15,000
Building, office.............................	-	-	[1] 57,600
Building, shop...............................	-	-	[1] 355,700
Building, warehouse..........................	-	-	[1] 17,300
Building, washhouse..........................	-	-	[1] 12,500
Shop, tools, and equipment...................	-	-	250,000
Office furniture and supplies................	-	-	50,000
Site preparation.............................	-	-	22,200
Roads (initial)..............................	-	-	225,000
Exploration..................................	-	-	66,000
Total....................................	-	-	10,195,900

[1] Prices include all materials and labor.

TABLE 62. - Depreciation schedule (Montana)

Item	Straight line depreciation, years	Yearly charge
Drills (overburden)	10	$59,600
Drills (coal)	5	5,800
Explosives truck	10	2,300
Dragline (overburden)	20	289,100
Wheel loaders (coal)	5	51,600
Trucks (coal haulers)	5	95,400
Supply truck	3	2,000
Sprinkler truck	10	3,200
Service truck (gas and oil)	10	3,000
Mechanic truck	5	1,200
Welding truck	10	800
Pickup trucks	3	7,000
Utility lift truck	10	2,400
Electrician truck	5	1,000
Scrapers	5	63,100
Motor grader	3	23,200
Dozers	5	61,800
Rippers, hydraulic for dozers	5	4,700
Pumps, sump	20	500
Towers, floodlight	20	900
Automobiles	3	2,500
Carryalls	5	1,800
Substation, power	20	2,500
Transmission line, power (initial installation)	20	800
Unit-train loading facility	20	50,000
Pump, casing and well	20	800
Buildings	20	22,200
Shop, tools, and equipment	20	12,500
Office furniture and equipment	20	2,500
Site preparation	20	1,100
Roads (initial)	20	11,300
Exploration	20	3,300
Subtotal	-	789,900
Depreciation for field indirect, engineering, overhead and administration, contingency, fee, and interest during construction	20	130,700
Total yearly depreciation	-	920,600

TABLE 63. - Manning table (Montana)

Personnel	Total	Wages per shift	Wages per year
PRODUCTION AND MAINTENANCE: 3 SHIFTS PER DAY, 7-1/4 HOURS PER SHIFT, 5 DAYS PER WEEK, 48 WEEKS PER YEAR			
Driller	18	$28.67	$123,900
Powderman	6	28.67	41,300
Loader operator	3	32.15	23,100
Truck driver, over 7-ton	9	28.67	61,900
Electrician	3	29.75	21,400
Motor grader operator	3	28.67	20,600
Crusher operator	3	28.67	20,600
Tippleman	3	29.03	20,900
Mechanic	6	29.75	42,800
Greaser-oiler	3	29.75	21,400
Labor, unclassified	6	27.58	39,700
1 SHIFT PER DAY, 7-1/4 HOURS PER SHIFT, 5 DAYS PER WEEK, 48 WEEKS PER YEAR			
Truck driver	1	$28.23	$6,800
Scraper operator	2	28.23	13,600
Dozer operator	2	28.23	13,600
Mechanic	4	29.31	28,100
Mechanic helper	2	27.86	13,400
Hostler	1	27.14	6,500
3 SHIFTS PER DAY, 8 HOURS PER SHIFT, 6 DAYS PER WEEK, 48 WEEKS PER YEAR			
Dragline operator	3	-	-
Weekdays[1]	-	$35.47	$33,200
Saturdays[2]	-	52.97	
Dragline oiler	3	-	-
Weekdays[1]	-	32.82	30,700
Saturdays[2]	-	48.99	
Dozer operator	3	-	-
Weekdays[1]	-	31.63	29,600
Saturdays[2]	-	47.26	
Subtotal	84	-	613,100
SUPERVISION: 8 HOURS PER DAY, 5 DAYS PER WEEK, 48 WEEKS PER YEAR			
Superintendent	1	-	$20,000
Assistant superintendent	1	-	15,000
Mine engineer	1	-	15,000
Assistant mine engineer	1	-	12,500
Office manager	1	-	10,000
Clerk	1	-	7,500
Warehouseman	1	-	7,500
Mine foreman	3	-	37,500
Master mechanic	1	-	14,000
Subtotal	11	-	139,000
Grand total	95	-	752,100

[1] 720 man-shifts per year (3 shifts per day, 240 days).
[2] 144 man-shifts per year (3 shifts per day, 48 Saturdays).

TABLE 64. - Estimated working capital (Montana)

Direct cost, 3 months	$188,000
Payroll overhead, 3 months	65,800
Operating supplies, 3 months	466,900
Indirect cost, 4 months	131,000
Fixed cost, 0.5 percent of insurance base	62,500
Spare parts	68,800
Miscellaneous expense	86,700
Total	1,069,700

TABLE 65. - Estimated annual production cost (Montana)

	Total annual cost	Cost per ton
Direct cost:		
Production:		
Labor	$479,500	$0.10
Supervision	100,000	.02
Subtotal	579,500	.12
Maintenance:		
Labor	133,600	.02
Supervision	39,000	.01
Subtotal	172,600	.03
Total direct labor	752,100	.15
Operating supplies:		
Explosives	850,600	.17
Fuel, lubrication, and hydraulic oils; grease and filters	111,000	.02
Spare parts	458,900	.09
Tires	150,300	.03
Office supplies	1,000	-
Miscellaneous	169,800	.03
Total operating supplies	1,741,600	.34
Power	126,000	.03
Payroll overhead (35 percent of payroll)	263,200	.05
Union welfare	1,000,000	.20
Rent, royalty, and strip license	1,150,000	.23
Subtotal	2,539,200	.51
Total direct cost	5,032,900	1.00
Indirect cost: 15 percent of direct cost and supplies	393,000	.08
Fixed cost:		
Taxes and insurance (2 percent of plant cost)	249,900	.05
Depreciation	920,600	.19
Deferred expense	347,000	.07
Total fixed cost	1,517,500	.31
Total annual production cost	6,943,400	1.39

TABLE 60. - Total estimated capital requirements (Montana)

Exploration, buildings, and roads	$1,071,300
Mining equipment	8,124,600
Unit-train loading facilities	1,000,000
Total direct	10,195,900
Field indirect	203,900
Total construction	10,399,800
Engineering	208,000
Subtotal	10,607,800
Overhead and administration	530,400
Subtotal	11,138,200
Contingency	1,113,800
Subtotal	12,252,000
Fee	245,000
Total plant cost (insurance-tax base)	12,497,000
Interest during construction	312,400
Subtotal	12,809,400
Working capital	1,069,700
Total capital requirements	13,879,100

TABLE 66. - Calculation of coal-selling price (Montana)

12 percent--20 years

R = $13,879,100/7.469 = $1,858,200

less depreciation -920,600

$937,600 = depletion + net profit

Depletion + net profit = 3/4 gross profit

Gross profit = 4/3 × $937,600 = $1,250,100

Sales = operating cost + gross profit
= $6,943,400 + $1,250,100 = $8,193,500

Selling price/ton--$8,193,500/5,000,000 = $1.64

Depletion = 50 percent of gross profit

F.I.T. = 50 percent of taxable income

Gross profit	$1,250,100
Depletion	625,050
Taxable income	625,050
Federal income tax (F.I.T.)	312,500
Net profit	312,550

Cash flow = net profit + depreciation + depletion
= $312,600 + $920,600 + $625,000 = $1,858,200

Appendix C

Alterations to U.S. Bureau of Mines IC 8632 to calculate longwall costs.

I. Alterations to table D-1, Capital Investment

Item	Quantity		Cost
continuous miner	5		$1,206,500
loading machine	5		322,500
shuttle car	10		593,000
roof bolter	5		213,000
auxiliary fan	20		60,000
mantrip vehicle	20		280,000
rock dusters (local)	10		35,000
rock dusters (machine)	5		133,000
section power center	20		460,000
section rectifier	20		40,000
section switch house	20		150,000
		total	$3,493,000
		savings	$10,492,000

II. Additional Longwall Investment

face supports	15		$17,250,000
stage loader	15		750,000
hydraulic drives	15		450,000
face conveyor (total)	15		2,925,000
shearer, double drum	15		3,540,000
control units	15		300,000
		increase	$25,265,000

Equipment change total increase (I&II) $14,773,000

III. Alteration of labor requirements table D-2.

Personnel	Quantity	Annual Cost
continuous miner operator	12	$133,760
loading machine operator	12	126,500
machine operator helper	12	126,500
shuttle car operator	24	231,880
roof bolter	24	253,000
bratticeman	12	114,619
utility man	12	119,536
mechanic	12	133,760
total	120	$1,239,556
decrease	540	$5,578,004

III. Continued,

Section foreman	51	$642,600
saving	15	$189,000

IV. Additional longwall crews

master controller operator	39	$434,720
shearer operator	78	869,440
chock operator	117	1,233,375
mechanic	39	434,720
timberman	78	822,250
utility man	39	388,493
total	390	$4,183,000
Net Change	-165	-$1,584,000/year

V. Financial Change

Capital Investment	$14,773,000
Labor Requirements	- 31,680,000
decreased cost	$17,000,000

at 5,000,000 tons per year for 20 years = 100,000,000 tons

savings per ton, $0.17